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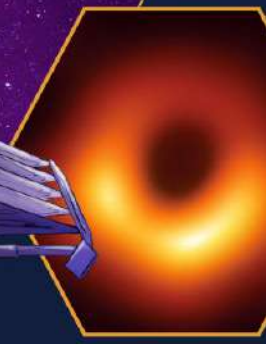

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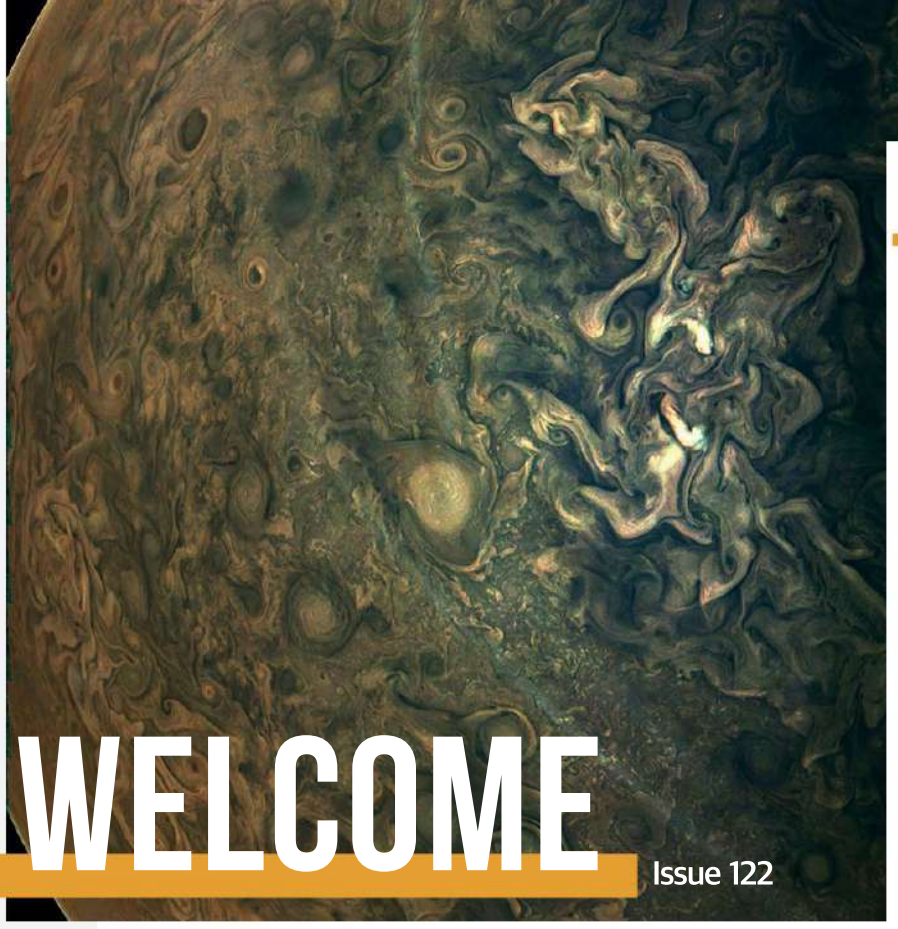

WELCOME

Issue 122

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Is the James Webb Space Telescope finally going to launch in 2021? According to NASA, and after completion of its final tests, the space agency is looking to release its revolutionary space telescope into space on 18 December 2021.

It's going to be a momentous occasion, and I can't wait to see what's been dubbed our premier deep-space observatory for the next decade finally make it into Earth orbit on board an Ariane 5 from Europe's Spaceport in French Guiana, on the northeastern coast of South America. As I write this, James Webb is currently getting ready to roll at Northrop Grumman's facilities in Redondo Beach in California.

Gregory L. Robinson, who serves as Webb's program director at NASA Headquarters in Washington DC, reflects on the journey from concept to near-launch: "[It's] an exemplary mission that signifies the epitome of perseverance. I am inspired by our dedicated team and our global partnerships that have made this incredible endeavour possible. Together we've overcome technical obstacles along the way, as well as challenges during the pandemic. Now that we have an observatory and a rocket ready for launch, I am looking forward to the big day and the amazing science to come."

GEMMA LAVENDER
EDITOR-IN-CHIEF

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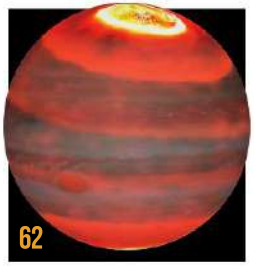
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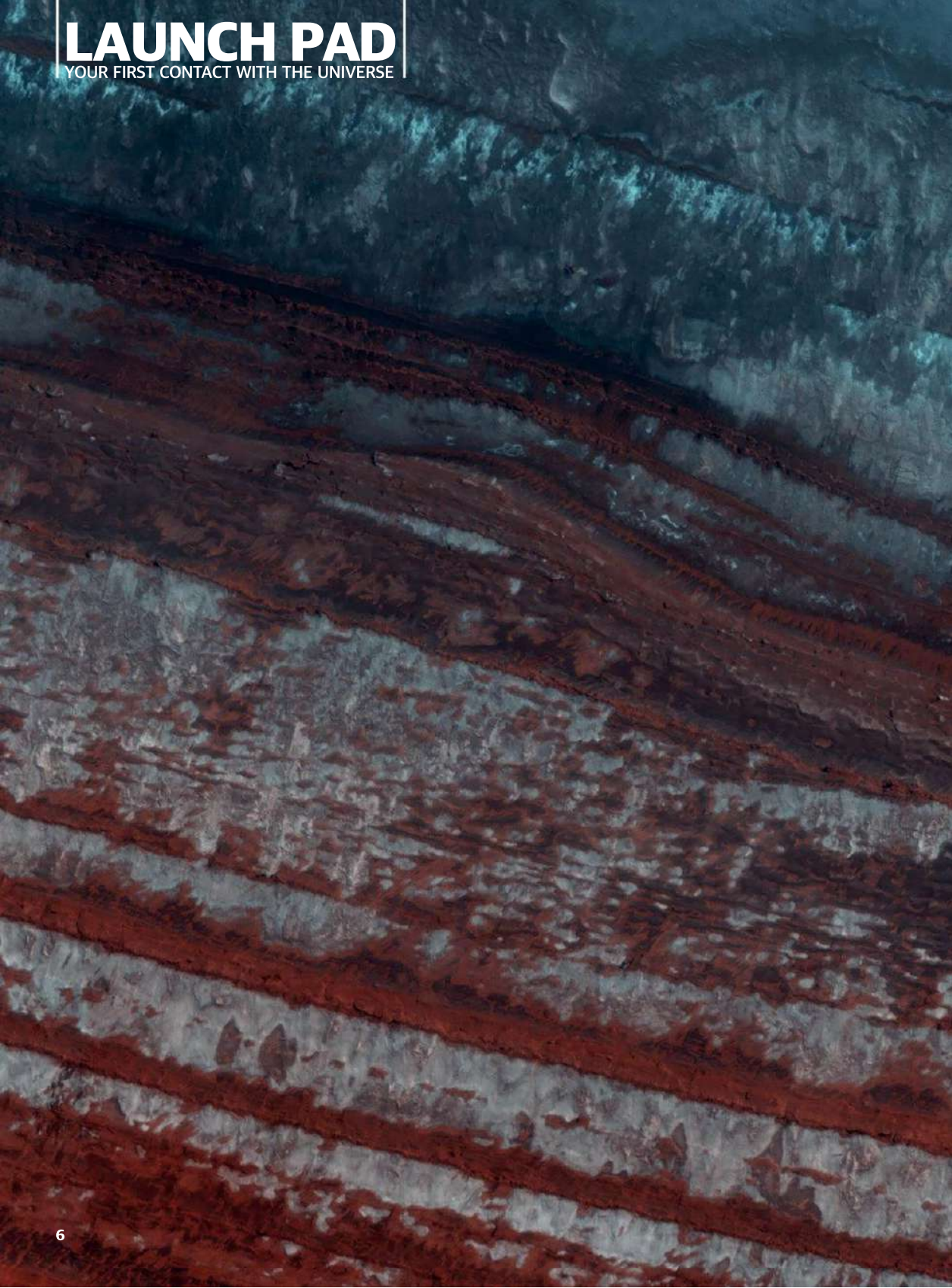

20 AUGUST 2021

Searching for Martian avalanches

The Mars Reconnaissance Orbiter captured this striking image of layered deposits of dusty water-ice in the northern polar region of Mars, known as the north polar layered deposits (NPLD). The layering is mainly caused by differing dust-to-ice ratios at the time of formation, and can give an insight into the Martian climate over time. Avalanches have also been observed at the edges of NPLDs, so these sites are carefully monitored, particularly in the spring, to determine the potential frequency and timing of 'avalanche season' on Mars.

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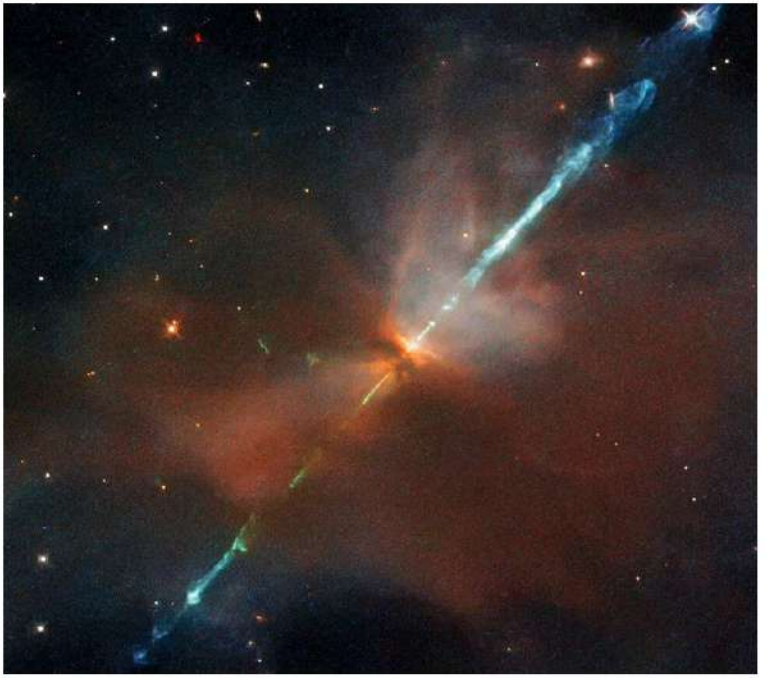

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30 AUGUST 2021

Flaming sword

Here a striking blue 'sword' appears to pierce a cosmic 'heart' made of gas and dust. The 'sword' is formed of two jets of superheated, ionised gas reaching out into space from opposite poles of a newborn star, called IRAS 05491+024. The powerful jets then collide with the clouds of gas and dust surrounding the newly formed star, creating a rare celestial sight known as a Herbig-Haro object. The one photographed here by the Hubble Space Telescope is called HH 111. It lies approximately 1,300 light years away in the constellation of Orion.

2 SEPTEMBER 2021

A helping hand

Megan McArthur, NASA astronaut and Expedition 65/66 flight engineer, takes a specialised augmented-reality headset for a test drive on the International Space Station. This new technology will help astronauts perform complex tasks autonomously, without guidance from Earth, and will be vital for deep-space exploration. Here McArthur is trying out Microsoft's HoloLens headset, delivered to the ISS in April 2021 as part of the T2 Augmented Reality (T2AR) experiment. The impressive headset runs a custom-built AR software that can help astronauts inspect and fix pieces of equipment without the need to call ground control or look up the instructions.

© NASA

13 SEPTEMBER 2021

Closer look at a shedding star

An enhanced image of AG Carinae has recently been released by the Hubble Space Telescope, showing the shedding star in even more detail. This new perspective was made possible by Hubble observations in 2010 and 2014, as well as images captured by the telescope's WFPC2 instrument in 1994. AG Carinae is a giant star on the edge of destruction, surrounded by an expanding nebula about five light years wide. AG Carinae is classified as a luminous blue variable, a fairly rare cosmic sight. These stars continuously lose mass during the final stages of their lives, only when enough mass has been lost will the star reach a stable state.

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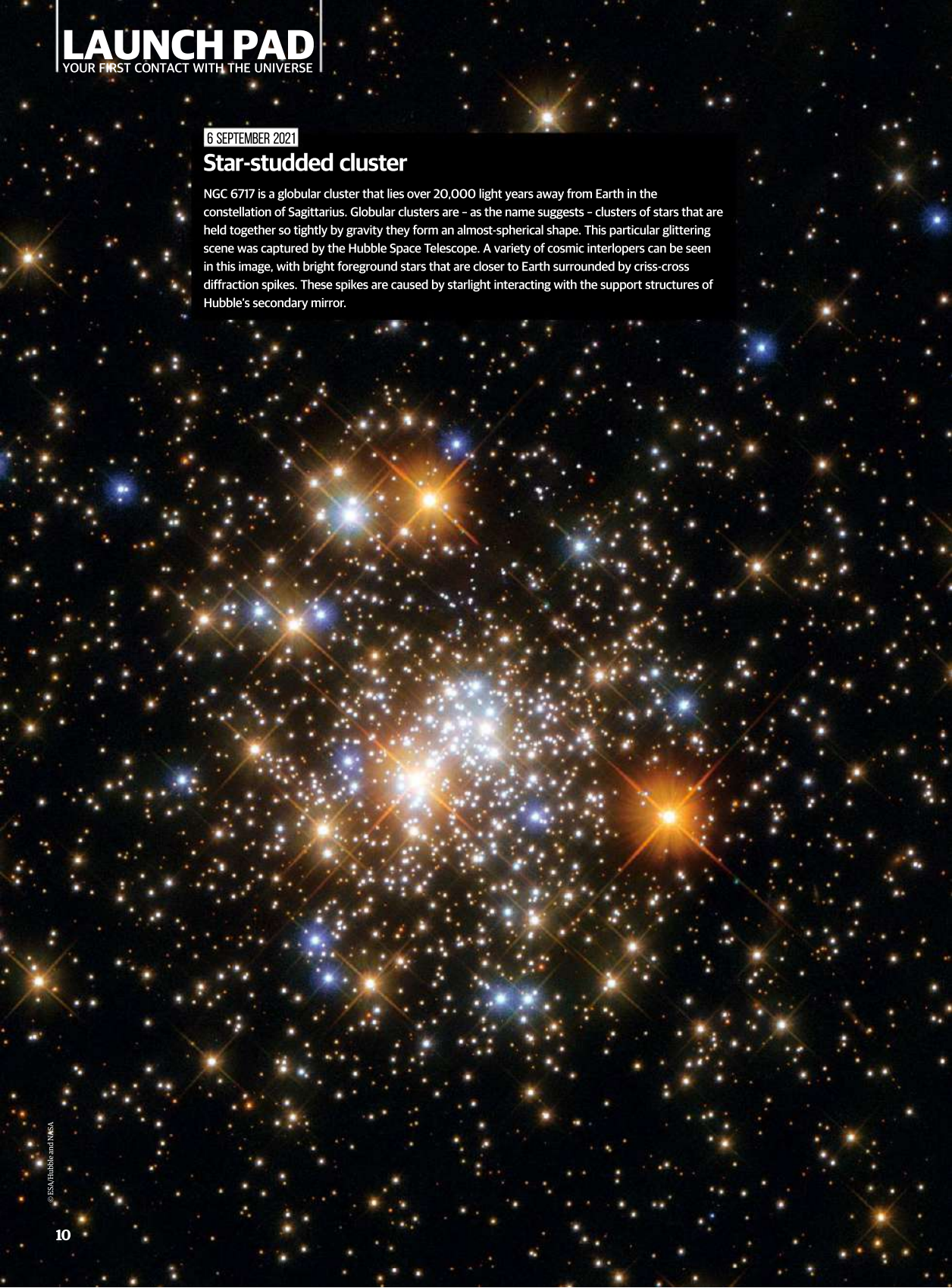
6 SEPTEMBER 2021

Star-studded cluster

NGC 6717 is a globular cluster that lies over 20,000 light years away from Earth in the constellation of Sagittarius. Globular clusters are – as the name suggests – clusters of stars that are held together so tightly by gravity they form an almost-spherical shape. This particular glittering scene was captured by the Hubble Space Telescope. A variety of cosmic interlopers can be seen in this image, with bright foreground stars that are closer to Earth surrounded by criss-cross diffraction spikes. These spikes are caused by starlight interacting with the support structures of Hubble's secondary mirror.



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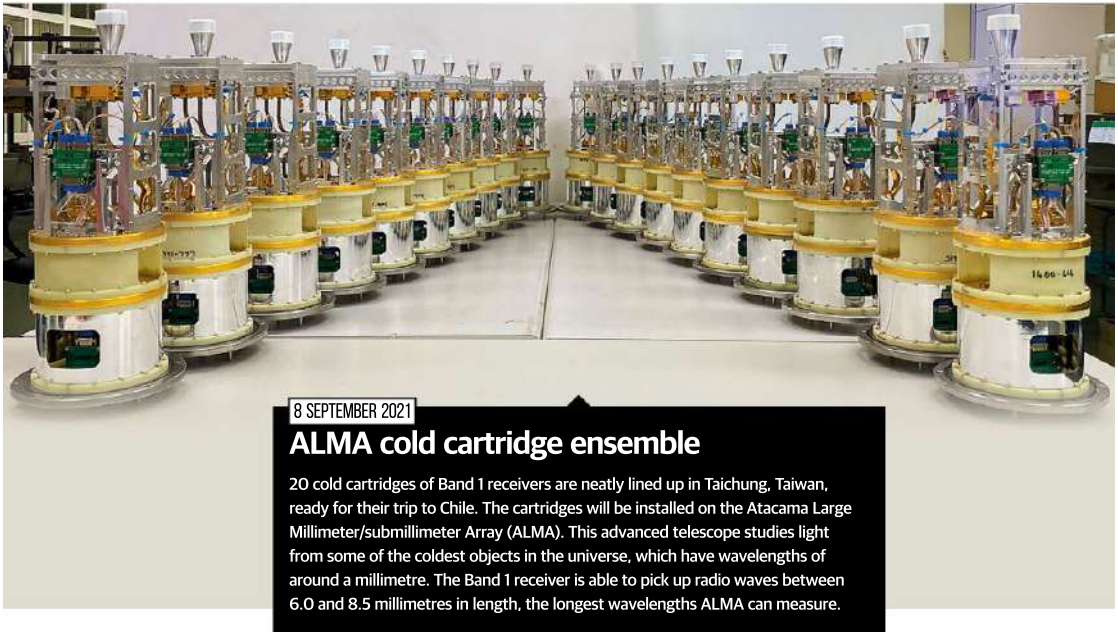
24 AUGUST 2021

Super Guppy

Ever wondered how NASA transports oversized cargo? Meet the Super Guppy cargo aircraft. The incredible whale-like aircraft is pictured here in the hangar at NASA's Armstrong Flight Research Center for maintenance work. The bulbous aircraft is equipped with a unique hinged nose that opens 110 degrees to help with cargo loading. Its impressive cargo area measures over seven metres (23 feet) in diameter and is almost 34 metres (111 feet) long. There are aircraft that can carry more weight than the Super Guppy, but very few come close to being able to carry anything as large.



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8 SEPTEMBER 2021

ALMA cold cartridge ensemble

20 cold cartridges of Band 1 receivers are neatly lined up in Taichung, Taiwan, ready for their trip to Chile. The cartridges will be installed on the Atacama Large Millimeter/submillimeter Array (ALMA). This advanced telescope studies light from some of the coldest objects in the universe, which have wavelengths of around a millimetre. The Band 1 receiver is able to pick up radio waves between 6.0 and 8.5 millimetres in length, the longest wavelengths ALMA can measure.

PERSEVERANCE HAS TAKEN THE FIRST STEPS IN MARS SAMPLE RETURN

Words by Meghan Bartels

Perseverance has begun its rock collection. The rover, designed to search for signs of ancient life on Mars and to package up material for a future sample-return mission, made its first two successful sampling manoeuvres on 6 and 8 September. NASA scientists describing the collection said they're thrilled with what they know so far about the two rock cores.

"This is a truly historic achievement; the very first rock cores collected on another terrestrial planet – it's amazing," said Meenakshi Wadhwa, Mars sample return principal scientist at NASA's Jet Propulsion Laboratory (JPL). "We've talked about Mars sample return for decades, and now it's actually starting to feel real. These first core samples will be among tens of other samples that will be collected by Perseverance."

The successes came after an initial sampling attempt a month prior that didn't go quite according to plan. On 6 August Perseverance drilled into a carefully selected rock, but failed to cache a rock core. Scientists troubleshooting the issue determined that the rock was unexpectedly crumbly, foiling the rover's sampling mechanism. At that point, the mission team's top priority was to confirm the sampling mechanism was working properly. After analysing the initial failure, Perseverance personnel pointed the rover to a new target that appeared to be less weathered and more robust.

The team's second rock selection, nicknamed 'Rochette,' proved more amenable. In the meantime, the engineers' excitement had spilled over to the geologists on the team. "As we were evaluating this target, the science team found this target to be of very high value as well," Jessica Samuels, Perseverance's surface mission manager at JPL, said.

As a result, the mission team decided to attempt to collect not one but two samples of Rochette, which the team are now referring to as 'Montdenier' and 'Montagnac'. Perseverance is equipped with 43 sample tubes, and because the rover will set up one or more stores of tubes during its mission, scientists have budgeted for taking multiple cores of rocks that they want to be positive can make it back to Earth, Perseverance deputy scientist Katie Stack Morgan of JPL said.

Because of the previous sampling misfire, Perseverance's human directors had the robot take extra photographs before attempting to store the first sample, Montdenier, adding to the uncertainty. "We were rewarded for our patience," Matt Robinson, Perseverance strategic sampling operations team chief at JPL, said. "Looking down the drill bit into the tube, you see a beautiful core there. At that point, our team was just absolutely ecstatic. I don't have words to say how we felt."

Both of the new samples come from the same boulder within Jezero crater, where the rover is exploring terrain that long ago hosted a lake. That rock is likely relatively young, and so far scientists have determined that the rock is basaltic, which means it may represent cooled lava that flowed along the Red Planet's surface.

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STRANGE RADIO SIGNAL NEAR THE CENTRE OF THE MILKY WAY HAS SCIENTISTS STUMPED

Words by Brandon Specktor

Astronomers have detected a strange, repeating radio signal near the centre of the Milky Way, and it's unlike any other energy signature ever studied. The energy source is extremely finicky, appearing bright in the radio spectrum for weeks at a time and then completely vanishing within a day. This behaviour doesn't quite fit the profile of any known type of celestial body, according to researchers, and thus may represent "a new class of objects being discovered through radio imaging".

The radio source, known as ASKAP J173608.2–321635, was detected with the Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope, situated in the remote Australian outback. In an ASKAP survey taken between April 2019 and August 2020, the strange signal appeared 13 times, never lasting in the sky for more than a few weeks. This radio source is highly variable, appearing and disappearing with no predictable schedule, and doesn't seem to appear in any other radio telescope data prior to the ASKAP survey.

When the researchers tried to match the energy source with observations from other telescopes – including the Chandra X-ray Observatory and the Neil Gehrels Swift Observatory, as well as the Visible and Infrared Survey Telescope for Astronomy in Chile, which can pick up near-infrared wavelengths – the signal disappeared entirely. With no apparent emissions in any other part of the electromagnetic spectrum, ASKAP J173608.2–321635 is a radio ghost that seems to defy explanation. Prior surveys have detected low-mass stars that periodically flare up with radio energy, but those flaring stars typically have X-ray counterparts. That makes a stellar source unlikely here.

Right: It's unlikely that a star is the culprit behind the odd signal

ISS ASTRONAUTS WILL SOON RESURRECT AN AI ROBOT FRIEND CALLED CIMON

Words by Tereza Pultarova

© Airbus

An AI-powered robot with a digital face is ready for a new mission on the International Space Station (ISS). The robot, called CIMON-2, short for Crew Interactive Mobile Companion, worked alongside two European astronauts on past missions to the station in recent years, and just got a software upgrade that will enable it to perform more complex tasks with a new human crewmate later this year.

The floating sphere with a cartoon-like face has been stored at the space station since the departure of the European Space Agency's (ESA) astronaut Luca Parmitano in February 2020. The robot will wake up again during the upcoming mission of German astronaut Matthias Maurer, who will arrive at the orbital outpost with the SpaceX Crew-3 Dragon mission in October.

Since the end of the last mission, engineers have worked on improving CIMON's connection to Earth so that it can provide a more seamless service to the astronauts, according to CIMON project manager Till Eisenberg at Airbus, which developed the intelligent robot together with the German Aerospace Center (DLR) and Ludwig Maximilian University of Munich.

"The sphere is just the front end," Eisenberg said. "All the voice recognition and artificial intelligence happens on Earth at an IBM data centre in Frankfurt, Germany. The signal from CIMON has to travel through satellites and ground stations to the data centre and back. We focused on improving the robustness of this connection to prevent disruptions."

Right: CIMON has been dormant for a year and a half, but has been upgraded

HOW IT WORKS

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OUR MILKY WAY GALAXY ISN'T VERY WELL MIXED

Words by Meghan Bartels

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Our galaxy isn't as thoroughly mixed as scientists assumed, according to a new study. The new research focuses on the distribution of what astronomers regard as metals, which is really just every element besides hydrogen and helium, even when these elements are gases. Scientists used the Hubble Space Telescope and the Very Large Telescope in Chile to map the metal in dust across the Milky Way in hopes of improving models describing the galaxy's history.

"Initially, when the Milky Way was formed more than 10 billion years ago, it had no metals," Annalisa De Cia, an astronomer at the University of Geneva in Switzerland, said. "The stars gradually enriched the environment with the metals they produced." That enrichment occurs because deep inside a star's core, atoms smash together to slowly form increasingly heavy types of matter, all the way up through iron. Not all stars explode when they run out of the material that fuels that process, but the stars that do go boom toss all those metals out into their cosmic neighbourhoods where, theoretically, the metals can mix in with the rest of the Milky Way.

Traditionally, scientific models have assumed that the mixing process is pretty effective. However, the new observations, which targeted dust near 25 different stars, suggest that might not be the case, and that instead there are stark local differences in metal levels. As a result, scientists may need to reevaluate their understanding of the Milky Way's history.

Above: A new study measured the distribution of metals throughout our galaxy

SUPER-PRECISE CLOCK TECH WINS PHYSICS BREAKTHROUGH PRIZE

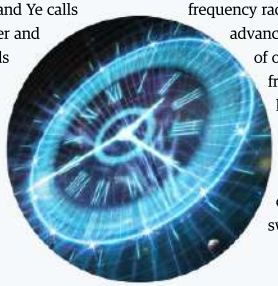
Words by Mike Wall

Two physicists just snagged $3 million (£2.16 million) for developing a super-precise clock that could allow scientists to study and explore the universe like never before. Hidetoshi Yatori and Jun Ye won the 2022 Breakthrough Prize in Fundamental Physics "for outstanding contributions to the invention and development of the optical lattice clock, which enables precision tests of the fundamental laws of nature".

Yatori is based at the University of Tokyo and Japan's Riken research institute, and Ye calls the University of Colorado Boulder and the National Institute of Standards and Technology home. The duo worked independently and will share the award.

Yatori and Ye's research was key to the creation of the optical lattice clock, which improves timekeeping precision by a factor of 1,000. The timepiece would lose less than one second if operated for 30 billion years – more than twice the age of the universe.

Optical lattice clocks are an evolutionary step beyond traditional atomic clocks, which are based on the quantum leaps made by electrons in energised atoms. 'One second' is officially defined as 9,192,631,770 cycles of the radiation that gets electrons in a caesium atom to make a quantum leap. Atomic clocks initially used microwave-frequency radiation to induce those leaps. An advance came with the substitution of optical light, which features frequencies about 100,000 times higher than microwaves. Those higher frequencies enabled greater timekeeping accuracy, just as they do in grandfather clocks which feature faster swinging pendulums.



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Left: This new way of timekeeping is the most accurate ever

Right: Named in honour of Crew Dragon's first passengers, the ships join SpaceX's vast fleet

IN COOPERATION WITH SPACE.com

SPACEX NAMES TWO NEW RECOVERY SHIPS AFTER NASA ASTRONAUTS

Words by Amy Thompson

The two newest members of SpaceX's recovery fleet sailed into Port Canaveral in September. The ships are named after Bob Behnken and Doug Hurley, the two NASA astronauts who were the first to fly inside a Crew Dragon. Their mission, known as Demo-2, was the final test flight of SpaceX's Commercial Crew Program, which blasted off from Kennedy Space Center on 30 May 2020. Its success cleared the way for routine astronaut flights to and from the ISS.

SpaceX has a fleet of recovery ships, each with its own purpose – from catching first-stage boosters to retrieving falling fairings. 'Bob' and 'Doug' will be a bit of both. The two multipurpose recovery ships are designed to handle a variety of tasks. 'Bob' and 'Doug' are former platform supply ships, which are designed to serve offshore platforms. SpaceX made modifications, including outfitting them with a large crane that can pull fairing pieces out the water. The new ships will also be able to help tow the drone ships out to sea, and will enable SpaceX to streamline its recovery efforts.

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To be in with a chance of winning, answer this question:

What does a cartographer do?

A: They paint pictures of aurorae

B: They create scientific maps, including those showing the constellations, stars and planets

C: They take photographs of the Sun

Competition ends on 4 November 2021

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JAMES WEBB SPACE TELESCOPE

NEW VIEW OF THE UNIVERSE

THE JAMES WEBB SPACE TELESCOPE IS FINALLY READY FOR LAUNCH – HERE'S THE LATEST ON THE LONG-AWAITED MISSION

Reported by Colin Stuart

Good things come to those who wait. Finally, the James Webb Space Telescope (JWST) should launch on 18 December 2021. Richard Ellis, of University College London, was on the original committee that pressed for the mission back in 1996. Back then, Hubble had been in space for six years, and was busy revolutionising the way we looked at the universe and our place within it. Yet there are some questions that even Hubble can't answer. "There's a horizon beyond which Hubble cannot see," says Ellis.

The space telescope was named after Edwin Hubble, who showed that the universe is expanding in the 1920s. As space swells, any light travelling through it also gets stretched. The light waves from the very early universe have been elongated to such a degree that they are now beyond the visible part of the electromagnetic spectrum. To see them you need an infrared telescope. But you can't build one on the ground because the heat of the Earth pumps out huge amounts of infrared radiation. You can't even put it 400 kilometres (248 miles) above the planet like Hubble. Instead Webb will observe the universe from 1.5 million kilometres (930,000 miles) away at Lagrange point L2, which is almost five times further from Earth than the Moon.

Ellis says that from this unique vantage point, we can finally "witness the birth of the first galaxies coming out of the darkness". Observing in the infrared is also a great way to observe star formation and the emergence of planets in the dusty discs that surround new stars. We can also peer into the atmospheres of alien planets to see if they contain substances that are important for life as we know it, such as water.

The need for these answers hasn't faded with time. "Here we are 25 years later, and these questions still stand," says Ellis. Astronomers' inquisitiveness hasn't gone away, but their patience has been sternly tested. It shouldn't have taken this long: the JWST was first slated to fly in 2007. In the years since we've had both a global financial crisis and a worldwide pandemic. Add to the mix engineering problems, political hesitancy and project management issues and you have a recipe for disaster. Some thought the day would never come, but now – a quarter of a century after it was first devised – Webb is finally heading for the coldness of deep space.

But despite the JWST's trials and tribulations to date, getting into space is arguably the easy bit. What comes next is some of the most ambitious spacecraft engineering ever attempted. To see all the way back to the birth of the first galaxies, Webb needs an enormous mirror. At 6.5 metres (21 feet) across, it's twice the size of any previous space telescope. The huge mirror is made of 18 hexagonal panels that fold up in order to fit it into a rocket. They are made of beryllium so as to ensure they are not too heavy to lift into space. Each segment weighs 20 kilograms – about the same as a suitcase you might take on holiday. This means that the JWST's mirror is just one-tenth the weight of Hubble's for a given area.

Once Webb gets to L2, those hexagonal panels have to unfold. The margin for error for aligning the panels is just 20 nanometres – a distance 5,000 times smaller than the width of a human hair. This delicate alignment can be thrown off by

> "[WE CAN FINALLY] WITNESS THE BIRTH OF THE FIRST GALAXIES COMING OUT OF THE DARKNESS"
>
> RICHARD ELLIS

2004

CONSTRUCTION BEGAN ON THE TELESCOPE'S DISTINCTIVE GOLD-PLATED MIRROR

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AR SCAN HERE

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WHAT WILL WEBB DO?

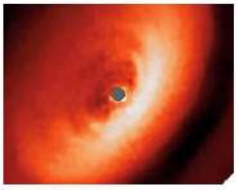
SPOT THE FIRST GALAXIES

The ongoing expansion of the universe has redshifted the visible light emitted by the first galaxies into the infrared. The JWST has the instruments and mirror diameter required to see them. It can also use spectroscopy to check that they only contain the nonmetal elements hydrogen and helium.

© NASA/ESA Hubble Space Telescope

STUDY STAR AND PLANET FORMATION

The formation of stars and planets generates a lot of heat, which is infrared radiation. As dusty discs of gas swirl around new stars, friction and collisions heat up the material as it coalesces into new planets. The JWST can watch this process in action and decipher the mysteries of exactly how it happens.



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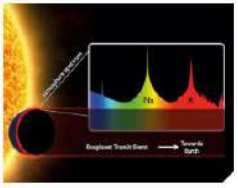
CHARACTERISE EXOPLANETS

We need to know what planets are made of if we're to understand the chances of them hosting life. We're looking for important chemicals such as water, which absorbs infrared light very efficiently. The JWST also carries a coronagraph to block out the host star's light for better views.



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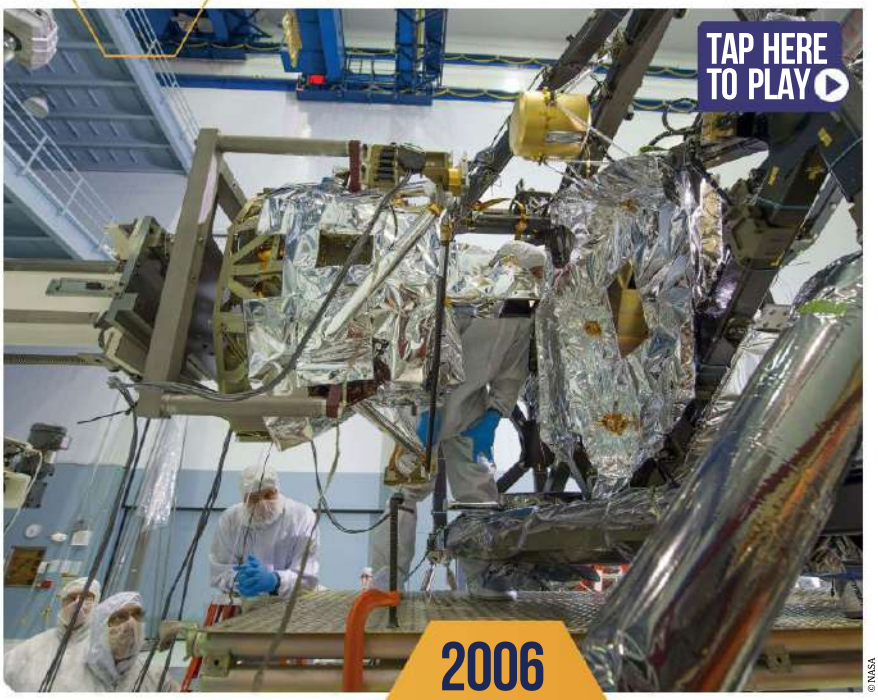


© NASA

2006

WEBB'S ESSENTIAL TECHNOLOGIES WERE TESTED SUCCESSFULLY UNDER FLIGHT CONDITIONS

small changes in temperature, so it also needs to deploy a five-layered sunshield the size of a tennis court in order to protect it from the heat of the Sun, Earth and Moon. It also helps keep the sensitive instruments on board operating at the sub-zero temperatures required to see in the infrared. According to Ellis, the danger that these intricate steps won't all execute properly is causing "a lot of anguish". We should know more by the end of the year. "Around Christmas time a lot of people will be biting their nails," he says.

Should the JWST's infrastructure deploy as planned, there's a real rush to squeeze in as many observations with the long-awaited telescope as possible. The situation is particularly acute because Webb has a pretty restricted shelf life. It's slated to operate for five years, with the hope that it may see out a decade; compare that to Hubble's 30 years and counting staring into space.

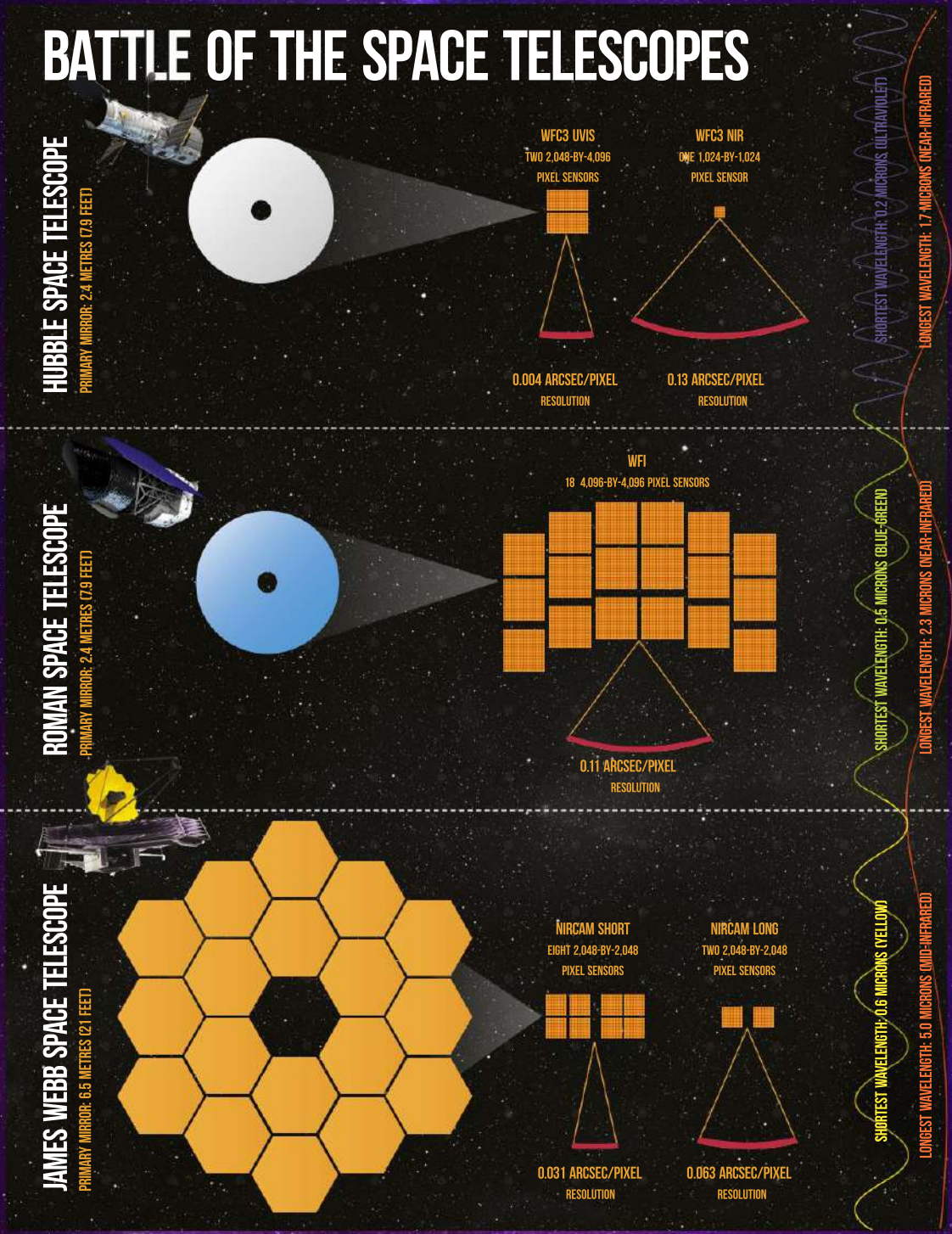
There are two key reasons why the JWST won't have the longevity of Hubble. The first is its sheer distance from Earth. Astronauts famously flew up and conducted spacewalks to fix Hubble when astronomers realised its mirror was the wrong shape. But that's not feasible when Webb is so far away. Sending astronauts there would shatter the record for the farthest humans have ever ventured.

The other issue is station-keeping. The JWST needs to stay at L2, and that requires constant nudges to keep it on course and ensure the instruments stay behind the sunshield. Those nudges will be provided by firing the Secondary Combustion Augmented Thrusters (SCAT) to jiggle the telescope into the right place. They rely on hydrazine fuel that is in limited supply – the JWST can hardly be refuelled at such an almighty distance from Earth.

According to Alistair Glasse, the instrument scientist for the JWST's Mid-InfraRed Instrument (MIRI), how much hydrazine the telescope has left for station-keeping depends on how smooth the journey out to L2 turns out to be. "If the launch doesn't go well and our initial burn to get out there isn't very good, then we could end up having to use more fuel than we would like," Glasse says.

"IT'S SLATED TO OPERATE FOR FIVE YEARS, WITH THE HOPE THAT IT MAY SEE OUT A DECADE"

BATTLE OF THE SPACE TELESCOPES



© NASA

2011

THE MIRRORS WERE FINISHED AND CRYOGENICALLY TESTED TO MIMIC THE COLDNESS OF SPACE

Even if the burn goes to plan, it'll take six months from launch before Webb is fully up and running. Glasse says that every minute of that half a year "has an activity scheduled, planned out and, in most cases, rehearsed". Suffice to say, it's a huge undertaking. Not only do the mirrors and sunshield need unpacking, the star-tracking equipment that helps with alignment needs testing, and only then can the team start to cool the instruments ready for the first observations.

Temperature is critical: to see in the infrared the telescope must give off as little heat of its own as possible. Low temperatures are usually measured on the Kelvin scale, where zero Kelvin is equal to absolute zero, the coldest possible temperature. It's the equivalent of -273.15 degrees Celsius (-459.67 Fahrenheit). The main parts of the JWST will be cooled to under 50 Kelvin, or -223 degrees Celsius (-369 degrees Fahrenheit) – that's about the same temperature as the surface of Pluto.

But Glasses' instrument, MIRI, needs to be even colder. Its infrared detector runs at a temperature just a few degrees above absolute zero. "In order to get that we need a bit of headroom," Glasse says. "The structure gets down to below five Kelvin." Given that the cosmic microwave background – the leftover radiation from the Big Bang – warms the universe by nearly three degrees, that's less than two degrees above the natural coldness of deep space. Should the helium cooling system fail – perhaps by springing a leak – MIRI would stop working above ten Kelvin, something Glasse says would result "in shedding a tear, or perhaps drinking a large glass of whisky". Maybe both.

But should everything go to plan, MIRI will be able to answer some of the biggest questions it's possible to ask about our universe. One of its main areas of focus will be spectroscopy. That's the technique of breaking light up into its constituent colours. Doing so often reveals missing colours called absorption lines – gaps in

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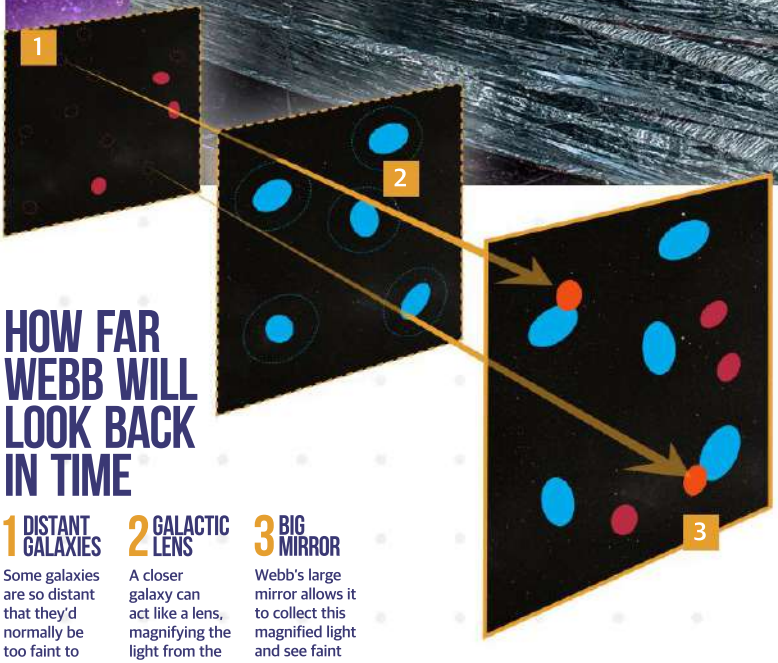


HOW FAR WEBB WILL LOOK BACK IN TIME

1 DISTANT GALAXIES
Some galaxies are so distant that they'd normally be too faint to detect.

2 GALACTIC LENS
A closer galaxy can act like a lens, magnifying the light from the distant galaxy.

3 BIG MIRROR
Webb's large mirror allows it to collect this magnified light and see faint distant galaxies.

"MIRI WILL BE ABLE TO ANSWER SOME OF THE BIGGEST QUESTIONS IT'S POSSIBLE TO ASK ABOUT OUR UNIVERSE"

2020

WEBB WAS FULLY FOLDED FOR THE FIRST TIME AND ITS SUNSHIELD DEPLOYED FOR THE FINAL TIME ON EARTH

© NASA

WHAT DELAYED THE JAMES WEBB SPACE TELESCOPE?

JULY 2011
THREAT OF CANCELLATION

US politicians threatened to pull the funding, but it was saved in November 2011.

27 MARCH 2018
SPACECRAFT ISSUES

Launch was delayed until March 2020 due to technical issues with the spacecraft.

27 JUNE 2018
REVIEW BOARD DELAY

After recommendation from an independent review board, launch was moved to March 2021.

16 JULY 2020
CORONAVIRUS

Launch was put back to October 2021 due to the impact of the COVID-19 pandemic.

1 JUNE 2021
ROCKET PROBLEMS

November 2021 became the new launch date after issues with the Ariane 5 launch vehicle.

8 SEPTEMBER 2021
LAUNCH DATE SET

The date was set for 18 December 2021 after a joint statement from NASA, the European Space Agency and Arianespace.

2019

ENGINEERS SUCCESSFULLY CONNECTED THE TWO HALVES OF WEBB TOGETHER

© NASA

the spectrum created when different chemical elements have swallowed that particular frequency of light. It acts like a barcode, telling us what celestial objects are made of. Often these absorption lines are in the infrared.

According to Glasse, one of the early targets for Webb will be Io, Jupiter's highly volcanic moon. It's home to around 150 volcanoes, which blast sulphur plumes up to 400 kilometres (248 miles) into space, something we should be able to see the absorption lines for. Planet formation is also a hot process, with collisions warming up dusty discs around new stars. Open questions such as how much solid material migrates through the disc, where giant planets form and how far out water turns to ice can also be tackled with the JWST.

Webb will also help us work out what the atmospheres of alien planets are made of. One way to find alien worlds is to watch a star get dimmer as a planet passes in front of it, in an event called a transit. If the transiting planet has a particular chemical in its atmosphere – say, ammonia – then the drop in brightness will appear more pronounced at ammonia's place in the spectrum, as it swallows up more of the star's light.

Water also devours infrared radiation, and the JWST can look for that directly in the atmospheres of hot exoplanets. There's a new class of planet recently labelled hycean – a name that comes from shunting the words 'hydrogen' and 'ocean' together. They are water worlds with hydrogen-rich atmospheres. The JWST will help us learn more about them, including whether they have the right

"WATER ALSO DEVOURS INFRARED RADIATION, AND THE JWST CAN LOOK FOR THAT DIRECTLY IN THE ATMOSPHERES OF HOT EXOPLANETS"

conditions for life, despite being very different places to Earth.

Spectroscopy will also help us discover more about the first galaxies to appear in the universe. The Big Bang created only hydrogen and helium, which astronomers call nonmetals. Every other chemical element came about as stars churned nonmetals into metals, making even more as they exploded at the end of their lives. This rich tapestry of chemistry was spread across the universe to be incorporated into new stars and new galaxies. To know that we really are looking at the first galaxies, we need to prove they have very few metals. The expansion of the universe has redshifted those absorption lines from the visible into the infrared, which is why we need the JWST to answer these questions.

If we were to sum up the point of the JWST in a single word, it would be 'origins'. Where did galaxies come from? How do stars and planets form? Are we the only life forms in the universe or has life had the chance to get started elsewhere? After two-and-a-half decades of delays, the wait may soon be over. We should all keep our fingers crossed that everything goes to plan and that the JWST successfully gets to work next summer. Our understanding of our place in the universe depends on it.

2021

WEBB WAS SHIPPED TO KOUROU, FRENCH GUIANA, FOR LAUNCH IN DECEMBER

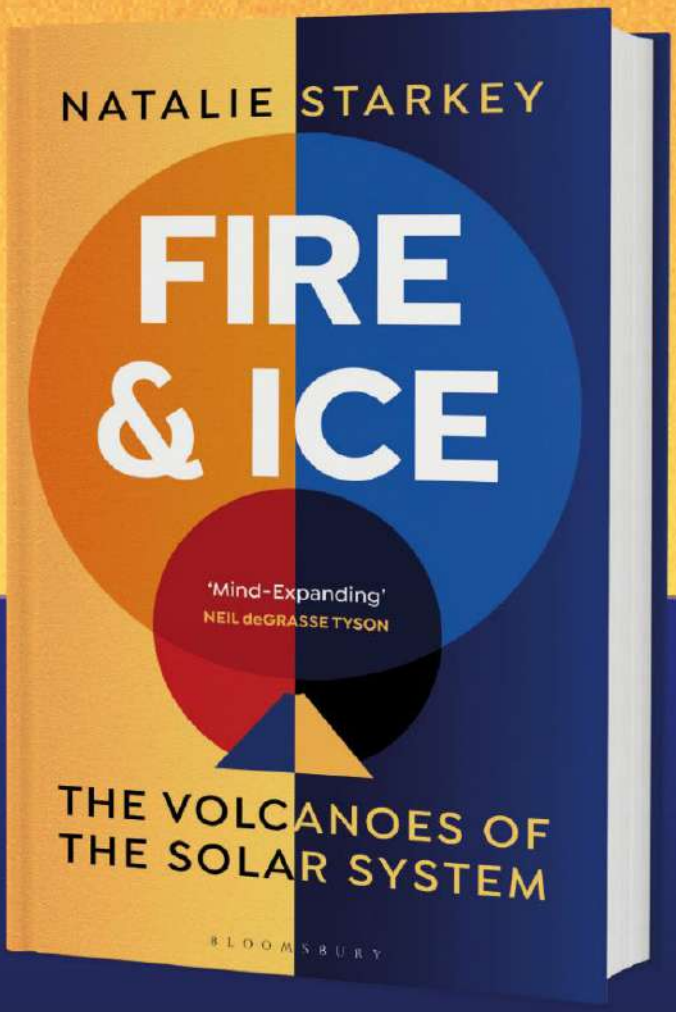
Colin Stuart
Science and technology journalist
Colin holds a degree in astrophysics, has written over 17 books on space and has an asteroid named in his honour: 15347 Colinstuart.

© NASA

Below: The team celebrates successfully completing upgrades to the Near InfraRed Spectrograph (NIRSpec)

© NASA

‘Mind-expanding’
Neil deGrasse Tyson



Exploring the Solar System’s volcanoes, from the highest peaks of Mars to the intensely inhospitable surface of Venus

BLOOMSBURY

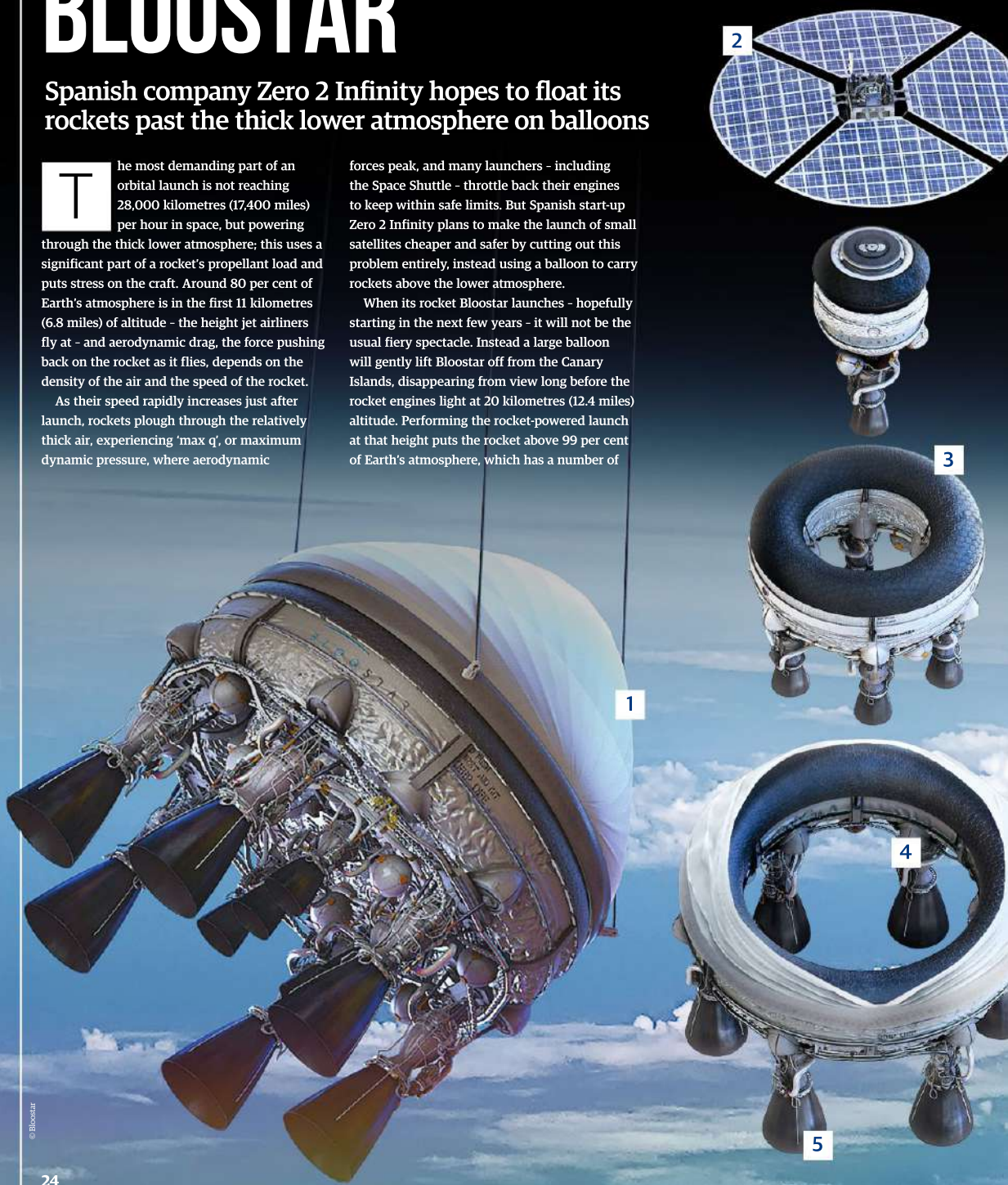
BLOOSTAR

Spanish company Zero 2 Infinity hopes to float its rockets past the thick lower atmosphere on balloons

The most demanding part of an orbital launch is not reaching 28,000 kilometres (17,400 miles) per hour in space, but powering through the thick lower atmosphere; this uses a significant part of a rocket's propellant load and puts stress on the craft. Around 80 per cent of Earth's atmosphere is in the first 11 kilometres (6.8 miles) of altitude – the height jet airliners fly at – and aerodynamic drag, the force pushing back on the rocket as it flies, depends on the density of the air and the speed of the rocket.

As their speed rapidly increases just after launch, rockets plough through the relatively thick air, experiencing 'max q', or maximum dynamic pressure, where aerodynamic forces peak, and many launchers – including the Space Shuttle – throttle back their engines to keep within safe limits. But Spanish start-up Zero 2 Infinity plans to make the launch of small satellites cheaper and safer by cutting out this problem entirely, instead using a balloon to carry rockets above the lower atmosphere.

When its rocket Bloostar launches – hopefully starting in the next few years – it will not be the usual fiery spectacle. Instead a large balloon will gently lift Bloostar off from the Canary Islands, disappearing from view long before the rocket engines light at 20 kilometres (12.4 miles) altitude. Performing the rocket-powered launch at that height puts the rocket above 99 per cent of Earth's atmosphere, which has a number of



© Bloostar

complementary advantages. Avoiding most of the drag losses means that the whole vehicle can be smaller, lighter and cheaper. As it avoids the stress of max q, it means the structures can be lighter, saving more propellant still, and these factors combined mean the design can be optimised around packaging the vehicle without major concern for aerodynamics, saving more mass and cost. Indeed, Bloostar looks like no rocket you'll have ever seen.

The first stage is formed of a doughnut-shaped tank carrying liquid oxygen and liquid methane – the same combination SpaceX is developing for trips to Mars. These propellants are pushed into six 10.6-tonne thrust engines purely by gas pressure in the tanks, avoiding the need for complicated turbopumps. Those engines are arranged around the ring-shaped tank structure, on top of which is a foldable, two-part, dome-shaped fabric canopy that protects the upper stages and payload.

Once the first stage has burnt out, this canopy folds open to clear the way for the second stage, another toroidal tank with a ring of six smaller rocket engines, burning liquid oxygen and methane, packed inside the middle of the first stage. After the second stage burns out, a third stage – packed in the hole in the middle of the second stage and powered by a single unit of the smaller engine – pushes satellites weighing up to 75 kilograms into a Sun-synchronous orbit some 600 kilometres (373 miles) high.

Packing the stages gives Bloostar a much larger volume for carrying payloads, and it makes the vehicle more compact and suited to the balloon launch, which will be carried out from the Canary Islands due to their stable wind conditions. The simplicity of the pressure-fed approach can also be continued with steering, as the six engines could be differentially throttled to control direction rather than steered around on gimbals. Bloostar could potentially make it into space with 12 small valves as the only moving parts in the whole system.

Though balloon launches aren't easy, Zero 2 Infinity has an ingenious concept in Bloostar that brings a genuinely novel approach to small space launches.

1 BALLOON
A large balloon, probably filled with hydrogen, will lift Bloostar above the thick lower atmosphere.

2 SATELLITES
Capable of lifting up to 75 kilograms in a well-proportioned payload fairing, Bloostar could lift a wide variety of small satellites into space.

3 TOROIDAL TANKS
Bloostar is built around doughnut-shaped composite tanks, allowing the vehicle to be stacked concentrically.

4 LOX-METHANE
Liquid oxygen and methane are becoming popular as they give better performance than kerosene and are without the challenges of super-cold liquid hydrogen.

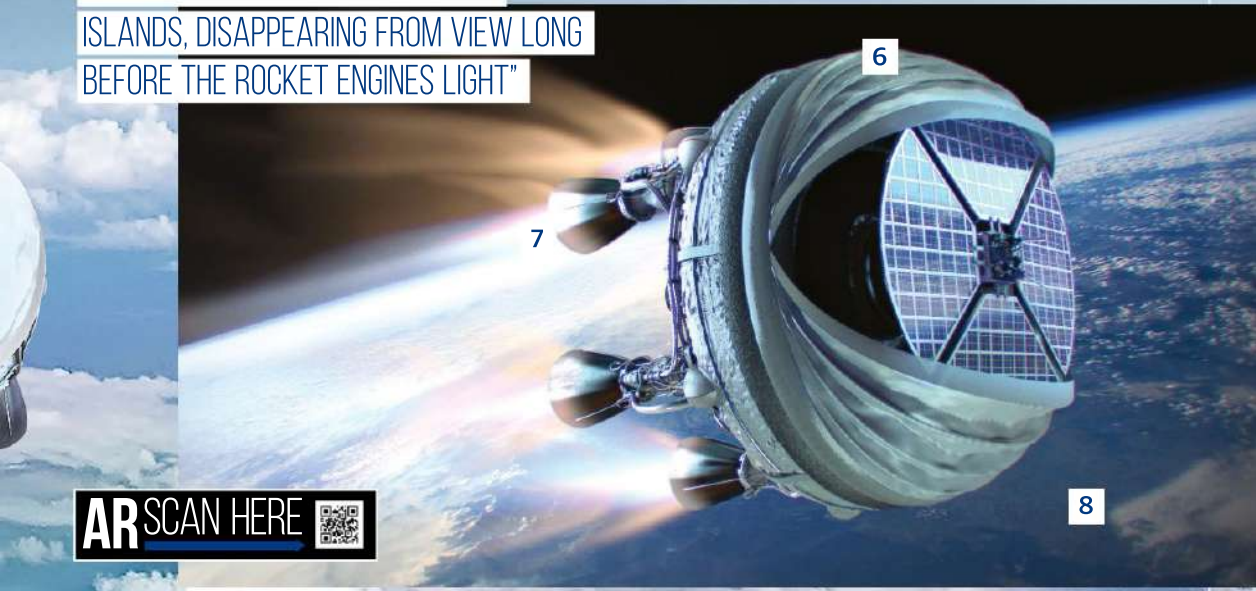
5 PRESSURE-FED ENGINES
All of Bloostar's engines are fed with propellants by the gas pressure in the tanks – like a water rocket – without complicated pumps.

6 COLLAPSIBLE CANOPY
Even at 20 kilometres (12.4 miles), Bloostar will need some aerodynamic shape. A flexible canopy provides this, which folds open ready for second stage ignition.

7 ALTITUDE
When it reaches 20 kilometres (12.4 miles), nearly twice as high as jet airliners fly – but only half the height Felix Baumgartner parachuted from – Bloostar will light its engines.

8 CANARY ISLANDS
A mid-ocean location, stable winds and a close proximity to Zero 2 Infinity's base in Barcelona make the Canaries the favourite location for liftoff.

"A LARGE BALLOON WILL GENTLY LIFT BLOOSTAR OFF FROM THE CANARY ISLANDS, DISAPPEARING FROM VIEW LONG BEFORE THE ROCKET ENGINES LIGHT"



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INTERVIEW

BIO

Leslie Kean

Kean is the author of *The New York Times* bestseller *UFOs: Generals, Pilots and Government Officials Go on the Record.* More recently she co-authored eye-opening articles in *The New York Times* that focused on sightings of UFOs, which the US military has recently rebranded as unidentified aerial phenomena (UAPs), and the government programs to investigate them. She also wrote *UFOs: Shifting the narrative from threat to science*, an article published in August 2021.

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LESLIE KEAN

"THE GOVERNMENT HAS ACKNOWLEDGED THE REALITY OF UFOS"

Kean is a veteran investigative reporter who has spent over 20 years delving into the once-taboo topic of unidentified flying objects (UFOs). But is the truth really out there?

Interviewed by Leonard David

How do you best characterise where we are today, given your *NY Times* co-authored piece that catapulted things into public view?
We have seen a major change since our December 2017 *New York Times* story that included two Navy videos. The government has acknowledged the reality of UFOs and the fact that they impact national security, and that alone is a major shift. We have more Navy videos of unexplained objects, an official UAP Task Force and most recently a government report on UAPs which was requested by the Senate Select Committee on Intelligence.

The report stated there is no evidence that UAPs are ours, Russian or Chinese. It forced many stove-piped agencies to pool information for the first time and gained further attention for UAPs from policymakers, with some calling for open congressional hearings. Even before the June 2021 UAP report, high-level officials have made statements as to the need for further investigation of these unexplained objects exhibiting technology beyond what we possess.

The taboo against taking the subject seriously is diminishing, and scientists have come out of the woodwork advocating for studies on UAPs. These events are unprecedented. And the media can't get enough of UFOs. Recently, for the first time, UFOs were covered by both *The New Yorker* and the CBS show *60 Minutes*.

Do you believe the 'UAP' focus is the same as decades of 'UFO' reports? Are they one and the same, or not, in your view?
I don't think there's any difference in how the reports describe the phenomenon. Government documents such as the famous 1947 Twining Memo describe the behaviour of the objects in the same way as later documents did, and in the same way they are reported today. The difference is that today we have better cameras, radar, satellite and sensor technology than we had decades ago, increasing the specificity of data on UAPs, which remains classified.

The term 'UAP' has gradually become the preferred term used by the government and military because it encompasses a broader range of phenomena than the term 'UFO'. But since 'UAP' came into use, primarily to avoid the stigma and baggage associated with 'UFO', there really isn't much difference between the two other than the impression the acronym creates. One seems more cultural; the other more official. 'UAP' removes any association with conspiracy theories, or shows like *The X-Files* or the fringe element. Even so, the term 'UFO' has been around forever and has a wider appeal. In my reporting I use the terms interchangeably, depending on the context.

Given your long and productive research on the UFO issue, what has surprised you the most? Similarly, what has disappointed you the most?
Especially in the early years of my reporting, I was most surprised by the lack of curiosity among scientists and policymakers about UFOs. I was also surprised by how entrenched and powerful the stigma was in the media and in culture in general. It mystified me why just about everyone wasn't impacted by the potential implications of the evidence for this phenomenon.

It didn't take long for me to realise that most people in a position to make a difference were uninformed, and understandably had other priorities. Still, given how fascinated I was with this, and given what it might mean if even one UFO was extraterrestrial, I found this apathy and disinterest hard to understand.

Many times I was amazed that accomplished investigative journalists did not jump on board and

© US Navy

© Getty

Above: A still from a US Navy video of a UFO sighting

Right: UFOs have cemented their place in popular culture and science fiction, but could they be more than that?

take a deep dive into this subject. As a freelancer I couldn't open the same doors as *The Washington Post*, *The New York Times* or *The New Yorker*. Yet they were essentially silent. That was frustrating to me, but it has all changed now.

I was also frustrated that there was no government agency in place to receive reports from police officers, commercial pilots and other credible witnesses, and to conduct investigations when necessary. You can imagine my surprise when I learned about the Advanced Aerospace Threat Identification Program (AATIP) in 2017. However, being limited only to military cases and being secret, it was not exactly what I had been hoping for.

With all the chatter now about UAPs, the UAP preliminary report and so on, where are we now, and what's next?

We have made tremendous progress in the last three-and-a-half years. There was a lot of momentum which built up prior to the release of the Office of the Director of National Intelligence (ODNI) UAP report on 25 June, and we have to keep that momentum going. But when things get quiet, I am aware that there is still a lot going on behind the scenes.

For our next steps, we need to have a well-funded task force with expanded staff that can access information from all government agencies and consolidate it. The best experts from many fields need to analyse this data. We need to understand the root of the intelligence failure which has stymied a meaningful government investigation into UAPs. Taskforce reports for the public and Senate committees need to continue to be published on a regular basis. And, of course, I believe that much more information should be released to the public.

There are videos and photographs in Department of Defense files which are vastly superior to the ones we have seen so far. I think the public has a right to this and other data, as stated by [former US] Senator Harry Reid, who initiated the [AATIP] government program. The secrecy is excessive here, despite the need for some classification on grounds of national security.

Perhaps we will be fortunate enough to see open congressional hearings on UAPs. Eventually, we may be issued a definitive statement that these objects are not Russian or Chinese. It has been established that they are not ours, but the door on UAPs being technology from a foreign adversary has not been completely closed. Some in a position to know have stated that these objects are not created by Russia or China. That needs to be stated as fact in one of the subsequent written reports. Perhaps one day those two countries will join with the US to acknowledge this reality. At that point, we will have crossed a line into a new world.

The public is experiencing a new wave of UFO frenzy – something we saw in the 1950s. There are those in this arena hard at work to make money. There are dedicated investigators trying to unravel this saga. What are your thoughts on how the public should be wary, but still remain open to getting to the bottom of the UFO story?

I would advise the public to be careful about who they listen to. Focus on official information provided by current and former government officials and others with credentials that are in a position to have knowledge. They often speak in generalities because they have been exposed to much classified information, and can only go so far in what they can say publicly. But their words carry a lot of weight and should be taken seriously.

> SCIENTISTS HAVE COME OUT OF THE WOODWORK ADVOCATING FOR STUDIES ON UAPS

I recommend paying attention to in-depth investigations, such as those from *The Debrief* and *The Drive*.

Fortunately, this subject transcends politics, and we have to keep it that way. We must all be wary of people with extreme conspiratorial views who are trying to influence the public for their own gain. Any such claims must be backed up with facts, names and documents that can be corroborated, or they are worthless. I encourage people to bear this in mind.

Do you expect 'full disclosure' regarding UFOs in the near term? If so, is the public ready for this disclosure and the related add-on of possibly distrusting the government?

It depends on what you mean by 'full disclosure'. Some people think this means that government officials will stand up and announce that we have been visited by extraterrestrial craft for over 70 years and we knew about it all along. I don't think this is ever going to happen.

If we get to a point where it becomes an official, stated fact, and universally accepted that these objects are not ours, Russian, Chinese or made by any country on Earth, this would be disclosure of at least some UFOs originating off this planet. At the same time, I suspect that tagged on to any admission along these lines would be the caveat that we don't know what they are, where they are from or why they are here. Such clarity will not necessarily be established in the near term.

It all goes in steps – sometimes small ones – and it takes time. I think the process will continue to be gradual disclosure, and this will help minimise distrust in government. It gives all of us time to absorb, explore and challenge each step along the way. We are closer than ever before to a new level of confirmation. Yet I am sure there is plenty of resistance to such a paradigm shift

Lastly, is there a need to 'internationalise' this UAP/UFO dialogue?

Definitely. Sources have told me that other countries have reached out to us since the June UAP report was released. China has established its own UAP task force. South America is active in investigating UAPs. International cooperation among government officials and among scientists is crucial in moving forward.

I believe that scientists need to follow the lead of Harvard's Avi Loeb and become more involved, initiating their own independent, international explorations of this phenomenon. They might be able to tell us more about it than our governments because they can make their results public.

Reported by Robert Lea

THOUGH IT WON'T HIT OUR PLANET FOR AT LEAST ANOTHER CENTURY, APOPHIS' SCIENTIFIC IMPACT IS TREMENDOUS

WILL AN ASTEROID HIT EARTH IN 2029?

© Getty

On Friday 13 April 2029, Earth will experience a dramatic close encounter with 99942 Apophis, with the 335-metre (1,100-foot) asteroid passing within 31,000 kilometres (19,000 miles) of our home planet, bringing it closer than most geostationary satellites. Thanks to Apophis' tremendous size, this close passage will be so bright that around 2 billion people will be able to witness it with the naked eye. First becoming visible in the Southern Hemisphere, the asteroid will resemble a speck of light as it streaks from east to west, initially passing over Australia, traversing the Indian Ocean and eventually crossing the equator over Africa.

This spectacular and historic event could have been much more severe. Scientists were unsure whether the passage of Apophis would result in a collision with Earth. Even when this risk was negated, researchers still couldn't rule out the possibility that Earth's gravitational effects could influence the asteroid in such a way that one of its next visits could result in an impact – something that was only ruled out this year.

"Apophis is in the category of potentially hazardous asteroids (PHAs) – asteroids with orbits that bring them very close to Earth now and for centuries in the future," says Richard Binzel, professor of planetary sciences at the Massachusetts Institute of Technology (MIT) and a leading scientist in the field of asteroid research. "What makes Apophis the poster

WHAT IS AN ASTEROID?

Asteroids are the shattered remains of planetesimals – objects that never grew large enough to become planets. There are millions of asteroids in the Solar System, distinguished from comets as they are formed from rock rather than dust and ice.

Comparing Apophis' height with two famous landmarks: the Empire State Building and the Eiffel Tower

© Getty

child for potentially hazardous asteroids is that it will make the closest known approach to Earth of any large asteroid this decade. But Apophis will miss the Earth."

Though we now know Apophis won't strike Earth in the near future, the fact that this asteroid has sat at the top of the European Space Agency's (ESA) 'impact risk list' of PHAs and NASA's Sentry Risk Table for 17 years – and its forthcoming visits – means its time as an object of intense scientific interest is just beginning.

Apophis was discovered on 19 June 2004 by Roy A. Tucker, David J. Tholen and Fabrizio Bernardi while they were working at the Kitt Peak National Observatory in Arizona, receiving the designation 2004 MN4. Though the team was only able to observe the asteroid for two days as a result of technical issues and unfavourable weather conditions, further observations quickly revealed a wealth of details about the asteroid.

In 2005 the asteroid was renamed 'Apophis' after the Greek name for an ancient Egyptian representation of evil and chaos, a serpent that dwells in darkness and frequently attempts to devour the Sun-god Ra as he makes his passage across the sky. In the same year that Apophis received its new moniker, Binzel was part of a team that used reconnaissance telescopic observations to measure the colour properties of Apophis and determine its composition, finding it resembles the most common class of meteorites, known as 'ordinary chondrites'.

Classified as an 'S-type', or siliceous asteroid, Apophis is composed mostly of silicates, with a mix of metals like nickel and iron. Its shape is believed to be elongated and comprises two lobes – almost like a rocky space peanut. "Apophis is a piece of an early Solar System planetesimal – a planetary building block – that never coalesced into one of our Solar System's planets.

"It has been stored in the asteroid belt for 4.6 billion years, and may be a fragment of a larger asteroid that broke apart in a collision in the asteroid belt," says Binzel. "That collision may have cast the fragment we call Apophis on a trajectory that resulted in its current orbit that comes very close to Earth."

The excitement of Apophis' discovery quickly turned to concern when researchers calculated just how close the asteroid's orbit would bring it to Earth. Using radar astrometry, researchers found a probability of around 2.7 per cent that the PHA would hit Earth in 2029. These estimates may seem low, but were still extreme enough to give Apophis the highest values on two systems used by astronomers to calculate how dangerous an asteroid is to our planet: the Torino scale, devised by Binzel, and the Palermo Technical Impact Hazard Scale.

By 2006 the probability of an impact in 2029 was all but negated, yet the threat presented by Apophis couldn't be as easily discounted. "Apophis will be so close in 2029 that Earth's gravity will significantly change its orbit. The trajectory of Apophis after 2029 depends on its exact position at the time of the encounter,"

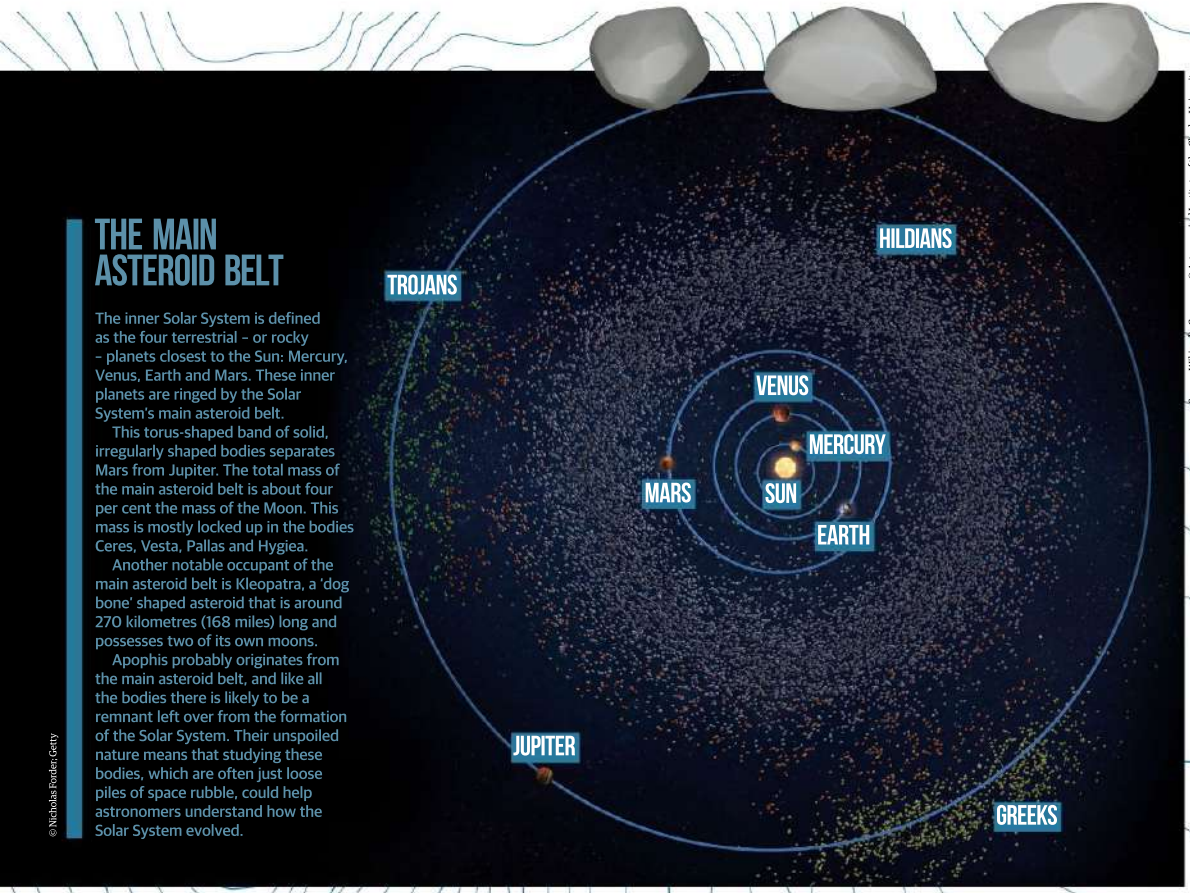
THE MAIN ASTEROID BELT

The inner Solar System is defined as the four terrestrial – or rocky – planets closest to the Sun: Mercury, Venus, Earth and Mars. These inner planets are ringed by the Solar System's main asteroid belt.

This torus-shaped band of solid, irregularly shaped bodies separates Mars from Jupiter. The total mass of the main asteroid belt is about four per cent the mass of the Moon. This mass is mostly locked up in the bodies Ceres, Vesta, Pallas and Hygiea.

Another notable occupant of the main asteroid belt is Kleopatra, a 'dog bone' shaped asteroid that is around 270 kilometres (168 miles) long and possesses two of its own moons.

Apophis probably originates from the main asteroid belt, and like all the bodies there is likely to be a remnant left over from the formation of the Solar System. Their unspoiled nature means that studying these bodies, which are often just loose piles of space rubble, could help astronomers understand how the Solar System evolved.



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Source: Wikipedia Commons © Astronomical Institute of the Charles University

says Davide Farnocchia, who joined NASA's Jet Propulsion Laboratory (JPL) in 2012, helping to conduct the analysis of the asteroid's trajectory. "If Apophis passed through specific gravitational keyholes, the gravity of Earth would tweak its orbit by just the right amount – or should I say the wrong amount – to put it on a collision course in a later year."

Even after a 2036 impact had been mostly ruled out – Apophis won't actually come that close to Earth during this passage – a gap in observations of the asteroid from 2015 to 2019, caused by its position close to the Sun, prevented an impact in 2068 or later from being dismissed. The asteroid seemed almost stubbornly determined to live up to its apocalyptic name. At least until this year, when Farnocchia and his team resolved to tackle the problem head-on.

"At JPL's Center of Near-Earth Object Studies (CNEOS), we compute high-precision trajectories and assess the possibility of future impacts for all known asteroids," says Farnocchia. "That's our daily bread and butter." But unseating Apophis from the top of various space agencies' 'risk lists' was no easy feat, and required a much better determination of the asteroid's orbit. To obtain this, Farnocchia and the CNEOS team took the results from a radar observation campaign and optical studies carried out in late 2020 and early 2021. They then combined these observations with previously collected data.

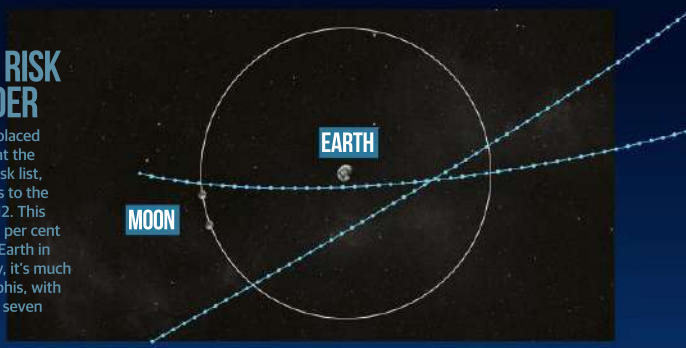
"Apophis has been extensively tracked since its discovery by both optical and radar telescopes," says Farnocchia. "Thanks to the data collected by astronomers all over the world, we can precisely predict the motion of Apophis through the April 2029 flyby." The team was able to calculate that the orbital period of Apophis will be stretched from 0.9 to 1.2 years as a result of its 2029 encounter with Earth.

Significantly, the CNEOS crew was also able to model how close Apophis will come to the gravitational keyholes that correspond to causing impacts in both 2036 and 2068. "The information provided by the 2020 and 2021 observations shrank uncertainties enough to ensure that Apophis will miss all the major gravitational keyholes in 2029," says Farnocchia, "allowing us to rule out any impact for the next 100 years." Breathing easier with the knowledge that Apophis won't strike our planet within the next century, we can speculate a little about the consequences of such a collision.

Considering what an impact between our planet and an asteroid the size, shape and

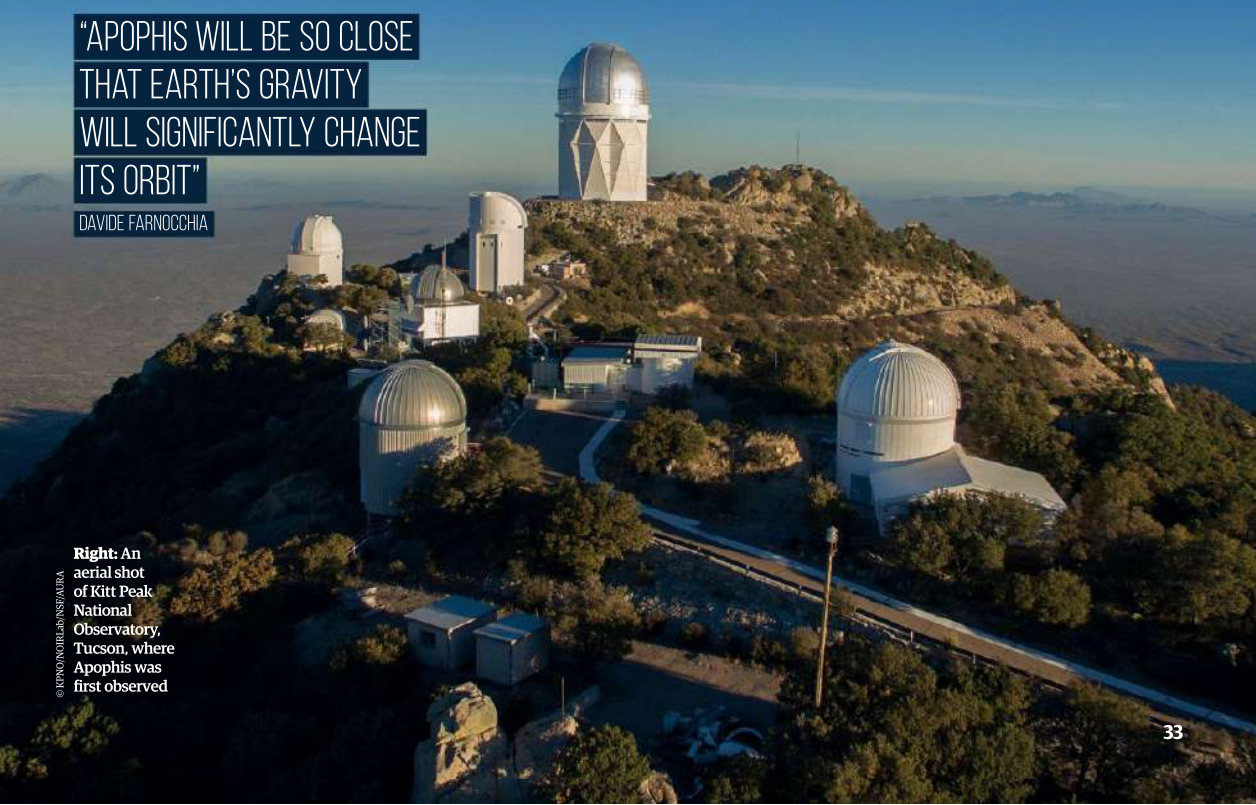
THE NEW RISK LIST LEADER

With Apophis displaced from its position at the top of the ESA's risk list, pole position goes to the asteroid 2010 RF12. This asteroid has a 4.6 per cent chance of hitting Earth in 2095. Fortunately, it's much smaller than Apophis, with a diameter of just seven metres (22 feet).



"APOPHIS WILL BE SO CLOSE THAT EARTH'S GRAVITY WILL SIGNIFICANTLY CHANGE ITS ORBIT"

DAVIDE FARNOCCHIA



Right: An aerial shot of Kitt Peak National Observatory, Tucson, where Apophis was first observed

© KPNO/NOIRLab/NSF/AURA

density of Apophis would look like is not an easy task. There certainly isn't anything like it in the geological record of our planet, and there are many factors that have to be considered when estimating the damage that could arise from such a collision. These factors include asteroid size, density and mass, as well as the angle and velocity at which the asteroid strikes.

Professor Gareth Collins from the Department of Earth Science and Engineering at Imperial College London studies impacts within the Solar System and is one of the developers of Earth Impact Effects, a program that allows users to input data from asteroids and create some estimates about an impact between our planet and that particular body. "We have run simulations of an impact between Apophis and Earth, but the outcome of an Apophis-scale impact with Earth is very uncertain," Collins says. "Size and speed are the main factors, but the nature of the target site is also important – if the impact occurs in the ocean it can generate hazardous tsunamis; on land, a lot more ejected dust is produced. And, of course, a major factor is how close the impact happens to human populations."

Collins estimates that if Apophis were to strike Earth at 20 kilometres (12.4 miles) per second – the average speed of asteroid impacts – the energy released would be about 10^{18} joules. "This is equivalent to the explosive yield of the global nuclear arsenal," he adds. "About 100,000 times more than the energy of the Chelyabinsk meteor and a million times more energy than the bombs dropped on Hiroshima."

The researcher goes on to explain that the worst-case scenario for an impact would be if it were to occur close to a large population centre or near a heavily populated coastline. If this occurred, devastating consequences would arise from a number of secondary effects, such as violent ground shaking to intense thermal radiation and atmospheric shock waves.

"Unless an asteroid similar to Apophis hits Earth and we can measure the consequences, our program will remain a 'best guess' and subject to large uncertainties," Collins adds. "But close

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AR SCAN HERE

THE DOUBLE ASTEROID REDIRECTION TEST

A NASA mission seeking to deflect deadly asteroids

1 WHAT IS DART?
The aim of the Double Asteroid Redirection Test (DART) mission is to slam into an asteroid and assess the effect on that object.

2 FIRST IMPACT
Testing the potential for planetary defence, DART will be the first time humanity has slammed an object in space with a kinetic impactor.

3 TARGET: DIDYMOS
DART's primary target will be the double asteroid Didymos, comprised of a 780-metre (2,550-foot) primary object and a 160-metre (525-foot) 'moonlet.'

4 WHY DIDYMOS?
Didymos has been selected for the DART mission because of its similarity to the asteroids that tend to threaten an impact with Earth.

COMPARING APOPHIS TO THE 'DINOSAUR KILLER'

The most infamous asteroid strike is that of the Chicxulub Impactor 66 million years ago. This 10 to 15 kilometre (6.2 to 9.3 mile) asteroid struck the Yucatán Peninsula in Mexico, generating an estimated energy equivalent to 21 to 921 billion Hiroshima bombs, wiping out the dinosaurs.

© NASA

Below: The Legacy Survey of Space and Time (LSST) conducted at the Vera C. Rubin Observatory will survey near-Earth objects

Because Apophis seems to be similar to around 80 per cent of the PHAs thus far identified by scientists, this means collecting data about these qualities grants researchers a unique opportunity to learn about a broad range of objects - and how we might divert them should they threaten Earth like Apophis once did. "Knowing how PHAs are put together might be some of the most valuable knowledge ever obtained in the event we ever have to put that knowledge to use to defend our planet from some future asteroid impact," Binzel adds. The true legacy of Apophis may be the insight it grants us, which might help successfully divert a PHA, meaning though this asteroid may never itself impact the Earth's surface, its scientific impact could be immeasurable.

Beyond this, however, the passage of Apophis in 2029 is a historic spectacle that shouldn't be missed. "Objects the size of Apophis come this close to Earth approximately once every thousand years on average," concludes Farnocchia. "Apophis is going to be so close in 2029 that it will be visible to the naked eye. It's going to be as bright as the stars in Ursa Minor. Don't miss the chance to see it... I know I won't!"

Robert Lea
Space science writer
Rob is a science writer with a degree in physics and astronomy. He specialises in physics, astronomy, astrophysics and quantum physics.

"SIZE AND SPEED ARE THE MAIN FACTORS, BUT THE NATURE OF THE TARGET SITE IS ALSO IMPORTANT"
GARETH COLLINS

approaches do help us better understand asteroids and their likelihood of striking Earth in future."

With the threat of an impact from Apophis negated for a while, researchers can now focus on the collection of scientific information from its flybys. With eight years of planning still remaining before the visit, the sky really is the limit for the Apophis investigation. "The 2029 flyby is a reminder that asteroids of considerable size can come close to and potentially reach Earth," says Farnocchia. "But the fact that we have known about this flyby since 2004 shows that our asteroid search-and-track programs and orbital calculations can allow us to discover and predict these events well in advance."

In particular, Farnocchia and his team will take advantage of this valuable scientific opportunity by observing how Apophis reacts to tidal forces when it gets so close to Earth. "Among other things, the rotation state of Apophis could change," says Farnocchia. "Apophis will extensively be observed from the ground, and high-resolution radar data will be collected. There are also spacecraft missions to Apophis under consideration to analyse the asteroid during and after the close encounter."

Observations of Apophis in 2029 should help scientists better ascertain its size, shape, composition and even model its interior. "By watching how Apophis might shake, rattle and roll, even just by a tiny amount, we will learn how it is put together on its inside," says Binzel, comparing this to how seismic waves travelling through Earth, the Moon and Mars have been used to model beneath their surfaces. "Interior structure for a potentially hazardous asteroid is something we have never measured before. Apophis might just give us that chance."

5

5 DART MISSION LAUNCH
DART is all set to launch aboard a SpaceX Falcon 9 rocket in November 2021. It will intercept Didymos in September 2022.

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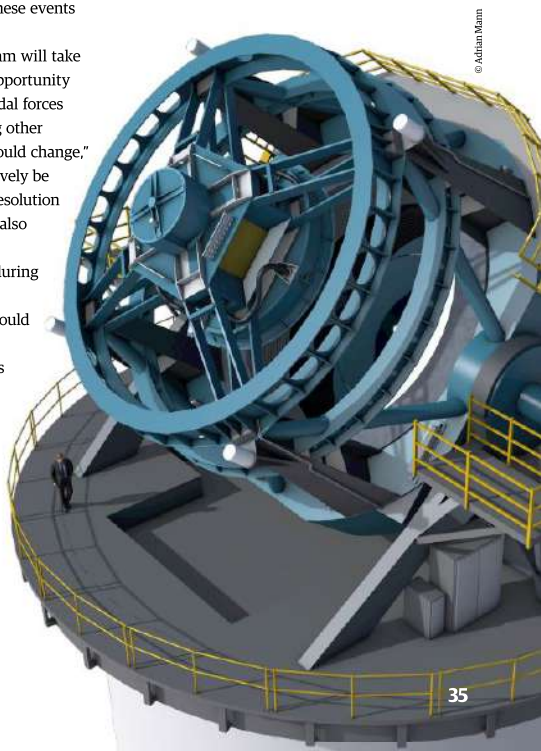

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NEW KIND OF STELLAR EXPLOSION SPOTTED?

Astronomers have uncovered evidence of explosions triggered by dead stars ramming into live ones

Reported by Charles Q. Choi

Supernovae are gigantic stellar explosions that can occur when stars die. These outbursts can briefly outshine all of the other suns in these dying stars' galaxies, making them visible from halfway across the cosmos. For decades, researchers have known of two main supernova types.

Large stars – more than ten times the Sun's mass – collapse in their centres when their cores burn all their fuel, causing the outer layers to explode and leaving behind a stellar remnant such as a neutron star or black hole. In contrast, stars less than eight times the Sun's mass burn out over time, leaving behind a dense core known as a white dwarf, and these remnants can pull fuel onto themselves off companion stars until they detonate in a thermonuclear explosion.

However, scientists have suggested other kinds of supernovae may exist. For example, most stars with more than eight solar masses are born in close orbits to companion stars. The heavier members of these pairs may die first as supernovae, leaving behind a neutron star or black hole that can theoretically spiral towards its partner and collide, triggering a supernova. Now astronomers may have discovered signs of such a merger-triggered core-collapse supernova.

"This is the first of a new class of supernovae," study lead author Dillon Dong, an astrophysicist at the California Institute of Technology, said. Using data from the Very Large Array Sky Survey (VLASS), a project that scans the night sky for radio outbursts, researchers detected an extremely luminous flare of radio waves, dubbed VT J121001+4959647, that happened in 2017. This outburst was not present in earlier radio surveys, and is "tied for the most radio-luminous supernova ever detected," Dong said.

Through follow-up radio and optical analysis, the researchers found the radio flare came from a star surrounded by a thick, dense shell of gas. This envelope of matter was likely ejected from the star a few centuries before the radio signals were emitted.

"The progenitor star had undergone an episode of eruptive mass loss, ejecting more than the mass of the Sun from its atmosphere," Dong said. The astronomers suggest the radio outburst happened when the star exploded in a supernova, with debris from the explosion crashing into the surrounding gas shell and generating a blaze of radio waves.

The scientists then examined previous X-ray data. They found that in 2014, X-ray jets erupted from about the same place as VT J121001+4959647. They suggest that these

Left: When stars explode, they release an enormous amount of energy

© Getty

"AS THE NEUTRON STAR OR BLACK HOLE SPIRALS IN, IT'S EXPECTED TO UNBIND A LOT OF THE STAR'S ATMOSPHERE AND EJECT IT OUT"

DILLON DONG

jets happened when a star went supernova, leaving behind a dead star that ripped gas off its companion, generating a dense gas shell. The luminous radio glow then occurred after the dead star rammed into its surviving partner. "As the neutron star or black hole spirals in, it's expected to unbind a lot of the star's atmosphere and eject it out to large distances," Dong said. "And if it reaches the core, theory predicts that it can disrupt fusion, trigger a supernova and launch the jets that we observed."

"I had no idea that we would find such a system in VLASS," Dong said. "But that's kind of the beauty of it - we looked with open eyes at every possibly interesting source and let our experience, particularly of dead ends we've gone down in the past, and our intuition point us towards the ones to look further into."

The scientists now plan to further monitor VT J121001+4959647 to learn more about how pairs of massive stars spiral towards each other, something that is extremely difficult to model with computer simulations, Dong said. "Systems like this may be our best handle on the physics of what happens when two stars merge."

More discoveries may lie in wait, Dong added. "One of the most exciting findings in astronomy of the past decade was that most massive stars are born in binary systems, triple systems, quadruple systems and so on, and most of them are close enough to have strong interactions within the lifetime of the star," Dong said.

"Where previously astronomers modelled these stars in isolation, we now realise that there is a rich set of phenomena to explore resulting from the interactions of these stars. A merger-triggered supernova, I think, is just scratching the surface of what's possible. With next-generation sky surveys and new developments in theoretical astrophysics, we may discover that stars behave in all sorts of unexpected ways."

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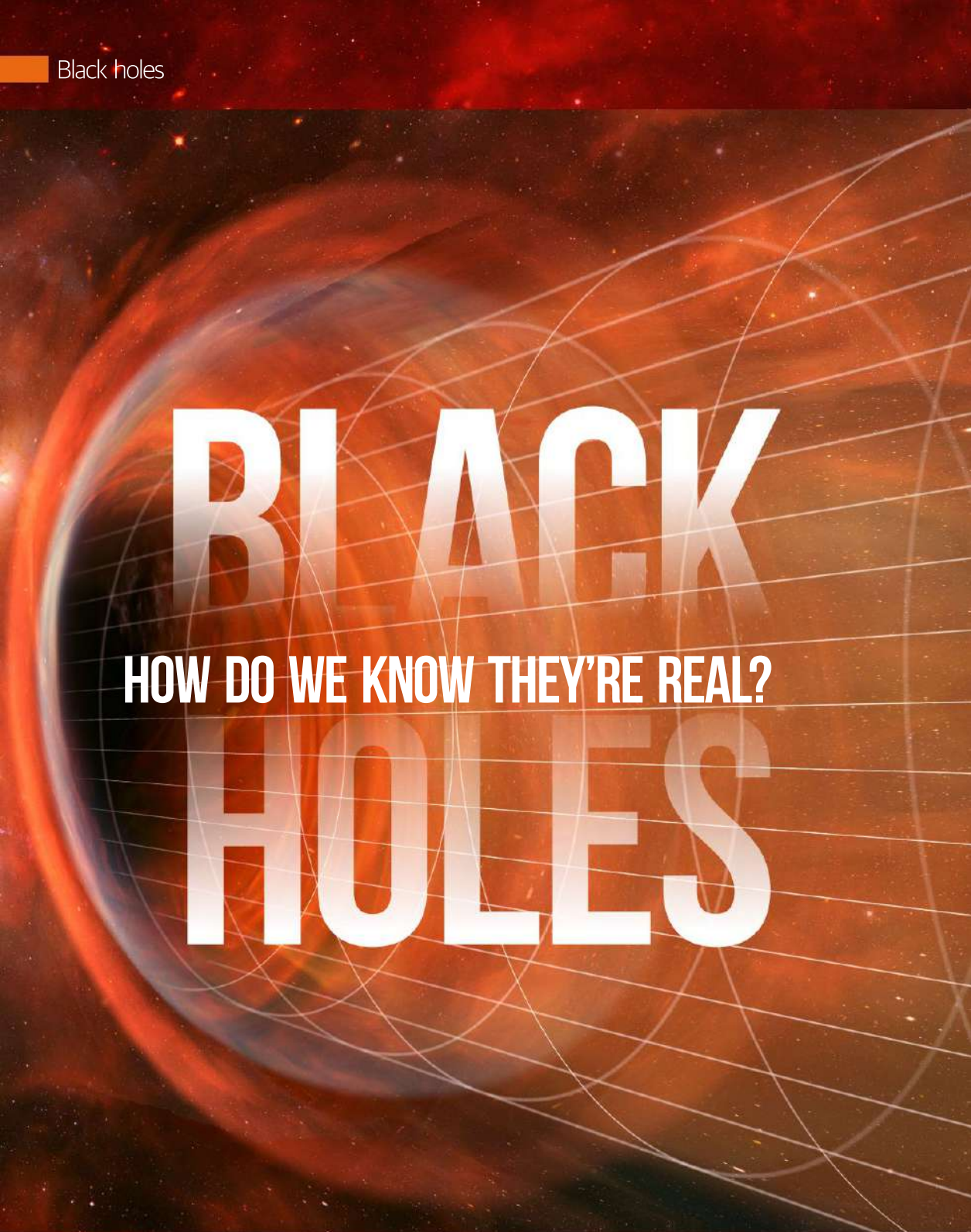


HOW DO WE KNOW THEY'RE REAL?

Reported by Andrew May

ONCE PURELY THEORETICAL, NOW THERE'S HARD EVIDENCE THESE HIGH-GRAVITY OBJECTS EXIST

Of all the far-out concepts in astronomy, black holes may be the weirdest. A region of space where matter is so tightly packed that nothing – not even light itself – can escape, these dark behemoths present a pretty terrifying prospect. With all the normal rules of physics breaking down inside them, it's tempting to dismiss black holes as the stuff of science fiction. Yet there's plenty of evidence – both direct and indirect – that they really do exist in the universe.

EINSTEIN'S 'ROBUST PREDICTION'

As a theoretical possibility, black holes were predicted in 1916 by Karl Schwarzschild, who found them to be an inevitable consequence of Einstein's theory of general relativity. In other words, if Einstein's theory is correct – and all evidence suggests it is – then black holes must exist. They were put on even firmer ground by Roger Penrose and Stephen Hawking, who showed that any object collapsing down to a black hole will form a singularity where the traditional laws of physics break down. This has become so widely accepted that Penrose was awarded a share in the 2020 Nobel Prize in Physics "for the discovery that black hole formation is a robust prediction of the general theory of relativity."

© Tobias Roetsch

EINSTEIN IS OFTEN CREDITED WITH PREDICTING GRAVITATIONAL WAVES, BUT HE WAS NEVER FULLY CONVINCED THEY WOULD EVER BE FOUND.

THEY CAN EMIT GRAVITATIONAL WAVES

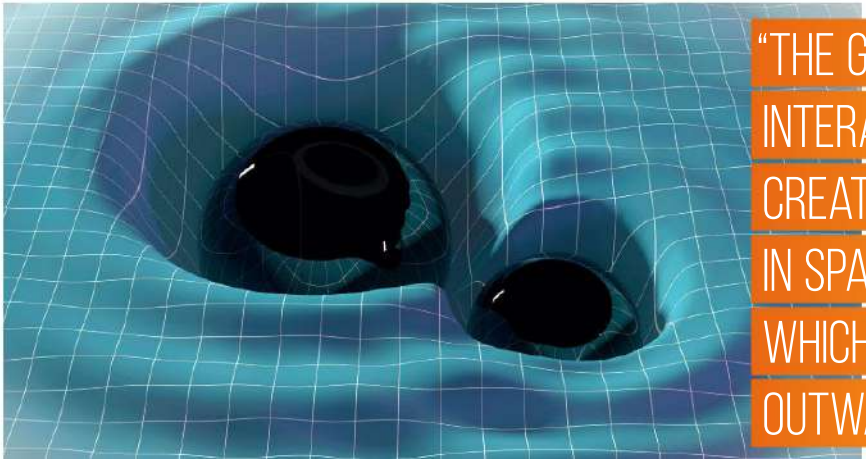
Black holes don't always exist in isolation; sometimes they occur in pairs, orbiting around each other. When they do, the gravitational interaction between them creates ripples in space-time, which propagate outwards as gravitational waves. With observatories like the Laser Interferometer Gravitational-Wave Observatory (LIGO) and Virgo, we now have the ability to detect these waves. The first discovery, involving the merger of two black holes, was announced back in 2016, and many more have been made since then. As detector sensitivity improves, other wave-generating events besides black hole mergers are being discovered, such as a crash between a black hole and a neutron star, which took place way beyond our own galaxy at a distance of 650 million to 1.5 billion light years from Earth.

© NASA/ESA

GAMMA-RAY BURSTS ARE EVIDENCE

In the 1930s, Indian astrophysicist Subrahmanyan Chandrasekhar looked at what happens to a star when it has used up all its nuclear fuel. The end result depends on the star's mass. If that star is really big, say, 20 solar masses, then its dense core – which may itself be three or more times the mass of the Sun – collapses all the way down to a black hole. The final core collapse happens incredibly quickly, in a matter of seconds, and it releases a tremendous amount of energy in the form of a gamma-ray burst. This burst can radiate as much energy into space as an ordinary star emits in its entire lifetime. And telescopes on Earth have detected many of these bursts, some of which come from galaxies billions of light years away, so we can actually see black holes being born.

GAMMA-RAY BURSTS WERE DISCOVERED ACCIDENTALLY IN 1967 BY A MILITARY SATELLITE DESIGNED TO MONITOR NUCLEAR WEAPON TESTS.



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"THE GRAVITATIONAL INTERACTION CREATES RIPPLES IN SPACE-TIME, WHICH PROPAGATE OUTWARDS"

THEY'RE A MASSIVE X-RAY SOURCE

The first observational evidence for a black hole emerged in 1971, and this too came from a binary star system within our own galaxy. Called Cygnus X-1, the system produces some of the universe's brightest X-rays. These don't emanate from the black hole itself, or from its visible companion star, which is enormous at 33 times the mass of our own Sun. Instead, matter is constantly being stripped from the giant star and dragged into an accretion disc around the black hole, and it's from this accretion disc that the X-rays are emitted. As was the case with HR 6819, astronomers used observed star motion to estimate the mass of the unseen object in Cygnus X-1. The latest calculations put the dark object at 21 solar masses, concentrated into such a small space that it couldn't be anything other than a black hole.

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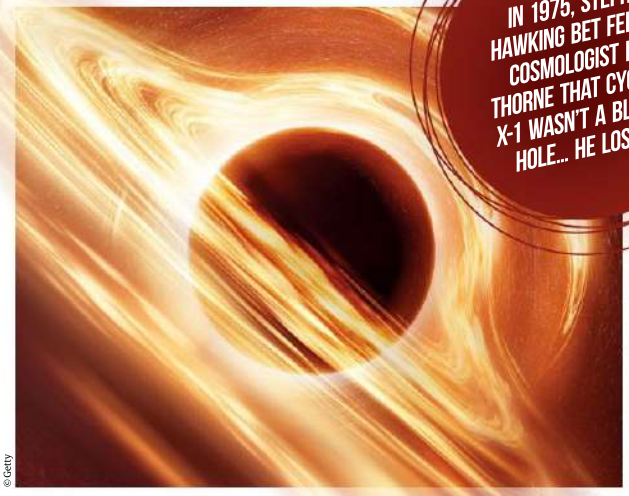
REINHARD GENZEL AND ANDREA GHEZ SHARED THE 2020 NOBEL PRIZE FOR DISCOVERING A SUPERMASSIVE BLACK HOLE IN THE MILKY WAY GALAXY.

THEY HAVE INVISIBLE COMPANIONS

There's one sure-fire way to detect these dark beasts, and that's through their gravitational effects on other stars. When observing the ordinary-looking binary system known as HR 6819 in 2020, astronomers noticed oddities in the motion of the two visible stars that could be explained only if there was a third totally invisible object there. When they worked out its mass – at least four times that of the Sun – the researchers knew there was only one possibility left. It had to be a black hole – the closest yet discovered to Earth, a mere thousand light years away inside our home galaxy.



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IN 1975, STEPHEN HAWKING BET FELLOW COSMOLOGIST KIP THORNE THAT CYGNUS X-1 WASN'T A BLACK HOLE... HE LOST.

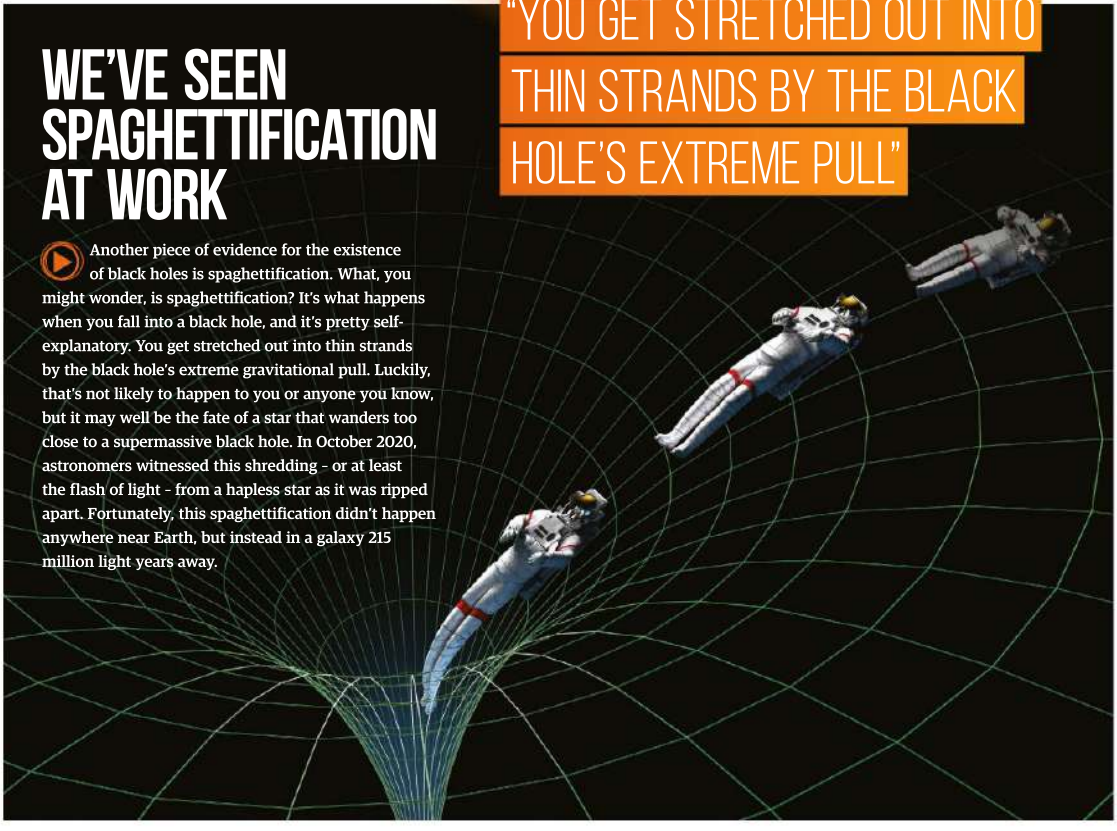
SUPERMASSIVE BLACK HOLES

In addition to black holes created through stellar collapse, evidence suggests that supermassive black holes, millions or even billions of solar masses, have been lurking in the centres of galaxies since early in the history of the universe. In the case of so-called active galaxies, the evidence for these heavyweights is spectacular. The central black holes in these galaxies are surrounded by accretion discs that produce intense radiation at all wavelengths of light. We also have evidence that our own galaxy has a black hole at its centre. That's because we see the stars in that region whizzing around so fast – up to eight per cent of the speed of light – that they must be orbiting something extremely small and massive.

WE'VE SEEN SPAGHETTIFICATION AT WORK

Another piece of evidence for the existence of black holes is spaghettification. What, you might wonder, is spaghettification? It's what happens when you fall into a black hole, and it's pretty self-explanatory. You get stretched out into thin strands by the black hole's extreme gravitational pull. Luckily, that's not likely to happen to you or anyone you know, but it may well be the fate of a star that wanders too close to a supermassive black hole. In October 2020, astronomers witnessed this shredding – or at least the flash of light – from a hapless star as it was ripped apart. Fortunately, this spaghettification didn't happen anywhere near Earth, but instead in a galaxy 215 million light years away.

"YOU GET STRETCHED OUT INTO THIN STRANDS BY THE BLACK HOLE'S EXTREME PULL"



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THE LARGEST KNOWN BLACK HOLE, DEEP INSIDE THE SHAPLEY SUPERCLUSTER, IS ESTIMATED AT ALMOST 80 BILLION SOLAR MASSES.

THERE'S A DIRECT IMAGE

So far we've had plenty of compelling indirect evidence for black holes: bursts of radiation, gravitational waves or dynamical effects on other bodies that couldn't have been produced by any other object known to science. But the final clincher came in April 2019 in the form of a direct image of the supermassive black hole at the centre of active galaxy Messier 87. This stunning photo was taken by the Event Horizon Telescope, which consists of a large network of telescopes scattered all over the world rather than a single instrument. The more telescopes that can participate, and the more widely spaced they are, the better the final image quality. The result clearly shows the dark shadow of the 6.5-billion-solar-mass black hole against the orange glow of its surrounding accretion disc.

TAP HERE TO PLAY

© Getty

Focus on

‘MOON IN A JAR’ RECREATES THE HAZY ATMOSPHERE OF SATURN’S MOON TITAN

The experiment has revealed previously unknown features of the satellite’s mineral make-up

Reported by Nicoletta Lanese

Titan is the second-largest moon in the Solar System and sports a dense atmosphere of mostly nitrogen, with a dash of methane. This yellowish haze hovers around -180 degrees Celsius (-290 degrees Fahrenheit). Below the atmosphere, lakes, seas and rivers of liquid methane and ethane cover Titan’s icy crust, particularly near the poles. And similar to liquid water on Earth, these natural gases take part in a cycle in which they evaporate, form clouds and then rain down on the moon’s surface.

Titan’s dense atmosphere, surface liquid and seasonal weather cycles make the frigid moon somewhat similar to Earth, and like our planet, the moon is known to have organic molecules that contain carbon, hydrogen and oxygen. Because of the organic chemistry taking place on Titan, scientists think the moon could serve as a massive laboratory to study chemical reactions that occurred on Earth before the emergence of life on the planet. But only one spacecraft, Cassini, has observed Saturn and its moons in detail, making it tough to do earthbound research on the wacky chemistry found on Titan. So a team of scientists set out to simulate Titan in a test tube.

The team first placed liquid water in small glass cylinders and cranked down the temperature to Titan-like conditions. This water froze to mimic Titan's icy crust. The team then introduced ethane to the tube, which became liquid like the lakes on Titan’s surface. Finally, they added nitrogen to stand in for Titan’s atmosphere, varying the temperature of the tube ever so slightly to simulate the variations in temperature on Titan’s surface and in different layers of its atmosphere.

The team then added two compounds called acetonitrile (ACN) and propionitrile (PCN). Data from Cassini suggests that these compounds are abundant on Titan, the experiment’s principal investigator Tomče Runčevski, an assistant professor in the Department of Chemistry at Southern Methodist University in Dallas, said.

Most of the previous studies examined these two compounds separately in their pure forms, but Runčevski’s team wanted to see what would occur when the compounds mixed and mingled, as they might on Titan. As opposed to working with each compound separately, “if you mix them together there might be a completely different outcome in structure, so how the molecules will organise, and how the molecules will crystallise,” or phase into a solid form, Runčevski said.

The team found that when both are present in Titan-like conditions, ACN and PCN behave quite differently than either compound in isolation: the temperatures at which the compounds

Below: An artist's impression showing the surface of Titan

"THE TEMPERATURES AT WHICH THE COMPOUNDS MELTED OR CRYSTALLISED SHIFTED DRASTICALLY,"

melted or crystallised shifted drastically. These melting and crystallisation points would be relevant in Titan's hazy, yellow atmosphere. The various layers of the atmosphere differ in temperature depending on their altitude above the moon's surface, so to understand how chemicals behave throughout the haze, the new study suggests that these temperature variations need to be taken into account, Runčevski said.

In addition, the team found that when ACN and PCN crystallise, they adopt different crystal structures depending on whether they're alone or in the presence of the other compound. Crystals form when the individual molecules within a compound snap into a highly organised structure. While the building blocks of that structure – the molecules – remain the same, depending on factors such as temperature, they can end up snapping together in slightly different configurations, Runčevski explained.

These variations in crystal structure are known as 'polymorphs'. When on their own, ACN and PCN adopt one polymorph at high temperatures and another at low temperatures. "What we notice is that if we have a mixture, the stability of the high-temperature and low-temperature [polymorphs] can be, in a way, switched," Runčevski said.

These fine details of when and how the compounds achieve a stabilised structure "can really change our understanding of what kinds of minerals we might encounter on Titan" in terms of what polymorphs they likely adopt on the moon, he continued. This can then shape what chemical reactions take place between these and other compounds on Titan.

The new study is limited in that it doesn't account for all of the chemicals present on Titan, and so can capture only a simplified picture of what actually happens on the moon. "It's important for us as scientists on Earth to create these models with increasing complexity, and one day to reach models that are really significant and can really help us further understand the surface of Titan," Runčevski said.

NASA's Dragonfly mission, set to launch in 2027 and arrive at Saturn around 2034, may provide more on-the-ground information about the mineral make-up of Titan. However, Runčevski suspects that the crystals his team observed likely form around the edges of Titan's lakes, cropping up as the liquid ethane in the lakes evaporates, leaving those compounds behind on the shoreline. At this stage, it's unclear whether the Dragonfly mission might focus on this specific aspect of the Titanian environment, but "nonetheless [the mission] is super exciting, and we will learn so much more about Titan," Runčevski said.

MISSION PROFILE

LUCY

NASA's Lucy mission will soon head to the Trojan asteroids in search of cosmic fossils

Mission type
Multiple flyby
Operator
NASA
Launch date
16 October 2021
Target
Trojan asteroids
Arrival at target
2027
Primary objective
To explore one main-belt asteroid and seven Trojan asteroids
Status
In progress

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Harold 'Hal' Levison
Lucy principal investigator
The Lucy mission is led by principal investigator Harold 'Hal' Levison from the Southwest Research Institute in Boulder, Colorado. He specialises in the formation and long-term behaviour of Solar System bodies, including comets, Kuiper belt objects and the Trojan asteroids.

Lucy is a NASA probe scheduled to launch on 16 October 2021. It will be the first-ever mission to explore a set of asteroids near Jupiter known as the Trojan asteroids. These ancient space rocks hold important clues to the creation of our Solar System and possibly the origin of life on Earth.

Along with a mission called Psyche, Lucy was approved in January 2017 as part of NASA's Discovery program, which supports focused and relatively cheap planetary missions whose development costs are capped at around $450 million (£328 million). A year after approval, the mission was officially given a schedule and a set of eight asteroid targets. Lucy is named for a famous female *Australopithecus afarensis* fossil found in Ethiopia that, as a relative of modern humans, helped illuminate the evolution of our species. It's hoped that the spacecraft will similarly elucidate our Solar System's earliest days.

Lucy spans more than 14 metres (46 feet) from tip to tip - larger than a four-storey building - though much of that will be the enormous solar panels used to power the spacecraft. The spacecraft will carry an instrument that can measure the surface temperatures of its target asteroids and provide information about their composition, two high-resolution cameras and a device that uses infrared light to inspect and identify ice, organic material and different minerals in each asteroid.

NASA is scheduled to launch Lucy on its planned 12-year mission on an Atlas V 401 rocket from Cape Canaveral in Florida. The total cost to launch the spacecraft is approximately $148.3 million (£108 million), which includes the launch service and other mission-related costs.

The probe's main objects of study are the Trojan asteroids. These objects are thought to be remnants from the primordial disc that formed the Sun and planets, captured by Jupiter's immense gravity soon after the gas giant's formation. Lucy will be the first mission to visit the Trojans, which are all named for famous figures from the Trojan war in Greek mythology. The Trojans share Jupiter's orbit around the Sun in two loose groups, with one set slightly ahead of the gas giant and another trailing behind it. The Trojans are stabilised by the Sun and its largest planet in a gravitational balancing act, keeping them in the same path.

After being launched from Earth, the spacecraft will first make a quick flyby of a main-belt asteroid in 2025. The small, rocky target is named 52246 Donaldjohanson after the palaeontologist who discovered the Lucy fossil. Situated between Mars and Jupiter, the flyby will serve primarily as a test for the spacecraft's instruments.

If all goes according to plan, between 2027 and 2033 Lucy will go on to fly past seven Trojan asteroids, including three different asteroid subclasses and two objects that rotate around each other. NASA has stated that "no other space mission in history has been launched to as many different destinations in independent orbits around our Sun". The mission's targets include C-type, D-type and P-type asteroids, each of which will help scientists better understand the Solar System's genesis.

During the 12-year mission, Lucy will travel almost 6.4 billion kilometres (4 billion miles) and will make three-and-a-half loops around the Sun. Remarkably, Lucy will travel out past Jupiter and then loop back to the vicinity of Earth for a final gravity assist that will send the spacecraft out to its final Trojan encounters. Lucy will perform these manoeuvres at average speeds of 643,737 kilometres (400,000 miles) per hour.

Lucy will also carry a mission plaque similar to those found on Pioneer 10 and 11 and the Golden Records on Voyager 1 and 2. The plaque features messages from individuals asked to provide words of wisdom, joy and inspiration to those who may read the plaque in the future. This cosmic time capsule features messages from world-renowned poets and artists, including Charles Simic, Rita Dove, Billy Collins and Beatles drummer-vocalist Ringo Starr to name but a few.

LUCY'S KIT

SPECIFICATIONS

Height: 7.2 metres (23.6 feet)

Width: 14.2 metres (46.6 feet)

Depth: 2.8 metres (9.2 feet)

Solar panel diameter: 7.3 metres (24 feet)

Launch mass: 1,550 kilograms, including fuel

HIGH-GAIN ANTENNA

This large two-metre (6.5-foot) antenna will beam back close-up images of the Trojan asteroids. The signal will also help scientists determine the mass of the asteroids by measuring changes in frequency caused by the Doppler effect.

TERMINAL TRACKING CAMERAS (T2CAM)

These tracking cameras will not only keep track of the asteroids during Lucy's encounters, but will also provide wide-field images of the targets to help scientists get a better idea of their shape.

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WHAT ARE C-TYPE ASTEROIDS?

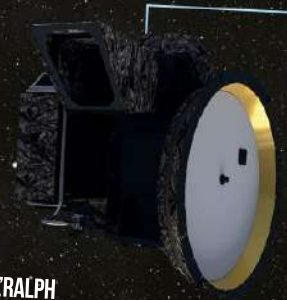
Lucy will fly past two C-type, or carbonaceous, asteroids: the main asteroid belt object Donaldjohanson and a Trojan named Eurybates.

C-type asteroids are rich in carbon and are where most meteorites on Earth originated from. The OSIRIS-REx and Hayabusa2 missions have previously collected samples from C-type asteroids to bring back to our planet for study.

WHAT ARE D-TYPE AND P-TYPE ASTEROIDS?

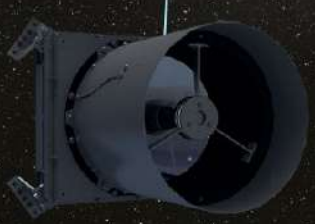
Lucy will also inspect two D-type asteroids, which are named Leucus and Orus, and three P-type asteroids, and a one named Polymele and a binary asteroid pair orbiting one another called Patroclus and Menoetius.

D-type and P-type asteroids appear much redder than C-type asteroids and are hypothesised to be rich in organic and volatile elements. No mission has ever flown past a D-type or P-type asteroid before.



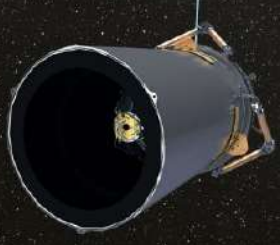
L'RALPH

This two-in-one instrument contains Lucy's colour camera, the Multispectral Visible Imaging Camera (MVIC) and the infrared-imaging Linear Etalon Imaging Spectral Array (LEISA) spectrometer, which will be used to find out what the asteroids are made from.



L'TES

The infrared Thermal Emission Spectrometer will remotely measure the surface temperatures of the target asteroids.



L'LORRI

The Long Range Reconnaissance Imager will capture high-resolution black-and-white images of the target asteroids. According to the Southwest Research Institute (SwRI), it's affectionately known as the 'eagle eyes' of the mission.

AR SCAN HERE

X4 Image © Southwest Research Institute (SwRI)

MISSION PROFILE

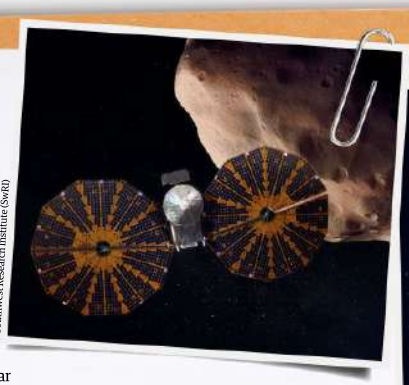
MISSION OBJECTIVES

Lucy aims to shed light on the history of our Solar System and explore the cosmic 'time-capsules' that are the Trojan asteroids, which may have been around since the birth of our Solar System over 4.5 billion years ago. Investigating this primordial material could even tell us about the kinds of materials that may have contributed to the early Earth. The asteroids are expected to provide a wealth of information, especially about the organic material that would have rained down on our planet in its earliest days, potentially helping to trigger the creation of living organisms. Each target is also thought to contain water ice underneath its rocky surface.

During the early Solar System, the primitive bodies that eventually formed into planets were compositionally diverse – as are the Trojan asteroids. To understand the diversity of the Trojan asteroids, Lucy will attempt to find out how old the asteroids are, as well as mapping their shape and the albedo of their surfaces. Lucy will also investigate the size and spatial distribution of craters on the target asteroids.

To find out what the asteroids are made of – including the distribution of minerals and ice – Lucy will map the colour and composition of the asteroids' surfaces using its myriad of specialised scientific instruments.

Lucy will measure the mass and density of the target asteroids and remotely investigate their interior properties. Lucy will be able to study the subsurface composition by observing material brought up to the surface through impact craters and fractures in the asteroids. Lucy will also keep an eye out for satellites and rings that might orbit the targeted Trojan asteroids, such as Queta that orbits Eurybates.



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Above: The massive solar arrays make up the bulk of the spacecraft and will provide it with power

Left: Some Trojans follow in Jupiter's path, while others orbit ahead of the gas giant

LUCY IN THE SKY WITH DIAMONDS... AND TROJANS

"EACH TARGET IS ALSO THOUGHT TO CONTAIN WATER ICE UNDERNEATH ITS ROCKY SURFACE"

LUCY'S TARGETS

Lucy will have an 'opportunistic trajectory' – one dictated by celestial mechanics so that a single spacecraft can reach a record number of asteroids for observation. Once Lucy has visited all eight targets, it will continue to cycle between the two Trojan asteroid groups every six years. Lucy's orbit will eventually become unstable, and it's likely Jupiter's gravity will cause the spacecraft to either be catapulted into the Sun or flung out of the Solar System.

52246 DONALDJOHANSON

Estimated diameter: 3.8 kilometres (2.4 miles)

A main-belt C-type asteroid located between Mars and Jupiter, scientists will test Lucy's instruments on this target before heading to the Trojans.

3548 EURYBATES

Estimated diameter: 68 kilometres (42 miles)

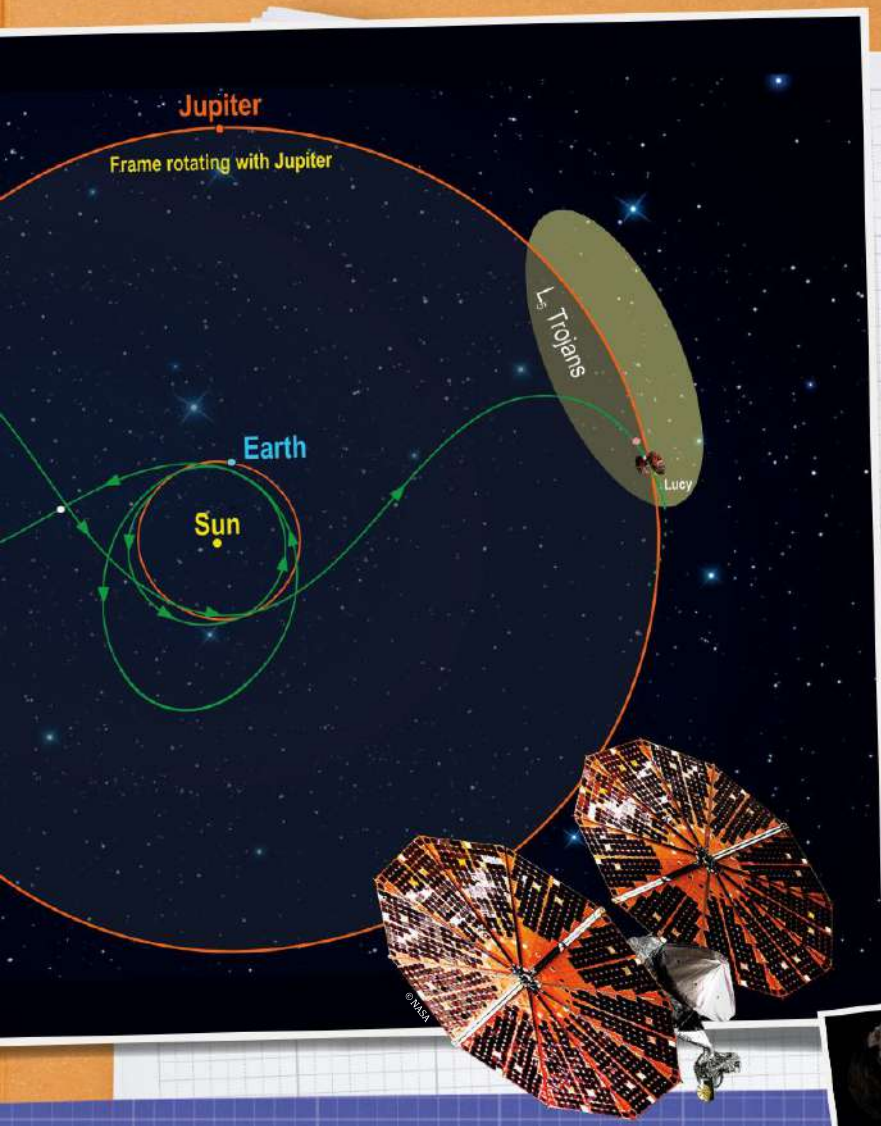
Eurybates will be Lucy's first Trojan target. The C-type asteroid is a giant remnant of a massive collision.

QUETA

Estimated diameter: One kilometre (0.6 miles)

Queta orbits Eurybates. On 9 January 2020 the mission team announced Lucy will be visiting this eighth target after discovering it.

x8 Images © NASA



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FLYBY TIMELINE

16 OCTOBER 2021
Lucy is scheduled to launch aboard an Atlas V 401 rocket from Cape Canaveral in Florida.

20 APRIL 2025
Lucy will observe its first and only asteroid in the main asteroid belt, Donaldjohanson.

12 AUGUST 2027
Lucy will observe Eurybates and its satellite Queta.

15 SEPTEMBER 2027
Lucy will observe Polymele.

18 APRIL 2028
Lucy will observe Leucus.

11 NOVEMBER 2028
Lucy will observe Orus before heading back towards Earth, then out towards Jupiter and the trailing L5 swarm.

26 DECEMBER 2031
Lucy will perform another Earth flyby, preparing the craft for its journey to the two remaining target asteroids.

2 MARCH 2033
Lucy will observe the binary pair Patroclus and Menoetius, marking the final flyby.

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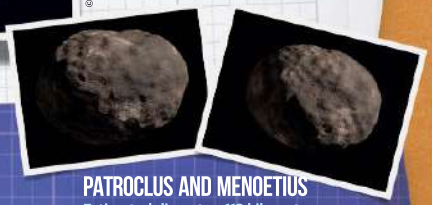

15094 POLYMELE
Estimated diameter: 21 kilometres (13 miles)
Lucy will attempt to fly within 399 kilometres (248 miles) of this P-type asteroid. It will be the first time a craft has ever flown by this class.

11351 LEUCUS
Estimated diameter: 40 kilometres (25 miles)
A D-type, it takes 446 hours to make a single rotation. The slow rotation means that Leucus likely gets hotter during the day and colder at night.

21900 ORUS
Estimated diameter: 51 kilometres (32 miles)
This D-type asteroid will be compared to the smaller D-type asteroid Leucus, and also to the similarly sized C-type Eurybates.

PATROCLUS AND MENOETIUS
Estimated diameter: 113 kilometres (70 miles) and 104 kilometres (65 miles) respectively
P-type Patroclus and Menoetius are binary asteroids thought to be relics from the very early Solar System. Lucy's final encounter with Patroclus and Menoetius is considered particularly special because the pair spend most of their time orbiting high above the main ecliptic plane of the Solar System, and are therefore hard to reach. The elusive asteroid pair will be passing through a region that is accessible to Lucy in March of 2033, when the spacecraft is scheduled to reach them.

ROGUE BLACK HOLES COULD BE WANDERING AT THE EDGES OF THE MILKY WAY

New simulations show these behemoths might dwell far from galactic centres

Reported by Ben Turner

An enormous number of rogue supermassive black holes may be wandering around the universe. In fact, wandering giant black holes may account for a whopping ten per cent of the nearby universe's black hole mass 'budget'. This means that galaxies like our own could have an average of 12 invisible behemoths prowling around their outskirts, gobbling up anything that gets in their way. Because the number of black holes increases the more mass there is in the outer 'halo' of material that surrounds galaxies, clusters of galaxies, which have heavy halos, could have even more of the ravenous wanderers.

Just as a basket can be woven around the supporting structure of a stone, astronomers think that most galaxies form around supermassive black holes. These gigantic gravitational beasts, often many millions or even billions of times more massive than the Sun, act as anchors for long trains of gas, dust, stars and planets that swirl in orbit around them. Closer to the black holes, this material spirals faster and heats up, forming an accretion disc that both feeds the black hole and produces the telltale radiation that makes it visible.

Usually the mass of the black holes cements them in the centres of their galaxies, which slowly orbit around each other in clusters called galactic groups. But sometimes an enormous force – such as a collision between two galaxies – can pop a central supermassive black hole loose, forcing it to wander the universe like a hungry cosmic vagabond.

These wandering monsters can also be set loose when the merging of two black holes is disrupted, sending them both flying. To estimate how often this occurs, astronomers ran a set of simulations called Romulus, which accounts for all known rules about how black holes behave to trace how their orbits might evolve over billions of years.

The simulations predicted that the frequent galactic collisions of the early universe, between the time of the Big Bang about 13.8 billion years ago and roughly 2 billion years later, produced enough wanderers to outnumber – and even outshine – their galactically fixed supermassive black hole cousins. Later, as the universe grew older, many of the loose black holes merged and were recaptured by other supermassive black holes after forming binary systems with them in the centres of galaxies, the simulations found. But many also remained free.

According to the astronomers running the Romulus simulation study, "Romulus predicts that many supermassive black hole binaries form after several billions of years of orbital evolution, while some SMBHs [supermassive black holes] will never make it to the centre.

"As a result, Milky Way-mass galaxies in Romulus are found to host an average of 12 supermassive black holes, which typically wander the halo far from the galactic centre." The researchers' next steps will be to figure out possible hallmarks of the lost invisible giants' presence in the universe so that one day soon we can observe them firsthand.

Below: The Milky Way could have up to 12 SMBHs lurking at its fringes

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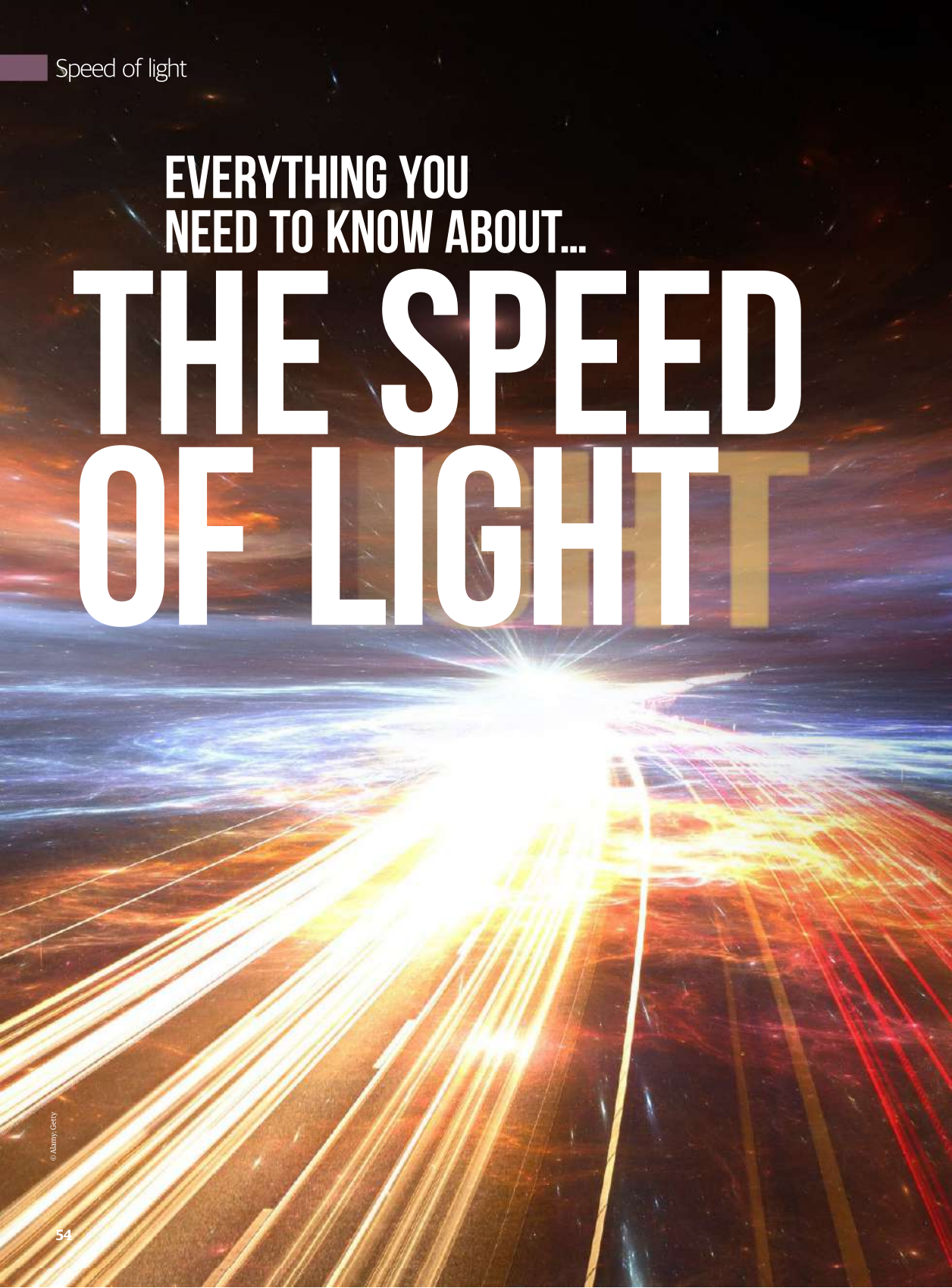
EVERYTHING YOU NEED TO KNOW ABOUT...

THE SPEED OF LIGHT



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THE SPEED OF LIGHT IS THE SPEED LIMIT OF THE UNIVERSE... OR IS IT?

Reported by Vicky Stein and Daisy Dobrijevic

Light travelling through a vacuum moves at 299,792,458 metres (983,571,056 feet) per second – a universal constant known in equations as 'c', or the speed of light. According to Einstein's theory of special relativity, nothing in the universe can travel faster than light. The theory states that as matter approaches the speed of light, that matter's mass becomes infinite. That means the speed of light functions as a speed limit on the whole universe.

The speed of light is so immutable that it's used to define international standard measurements like the metre. Through some crafty equations, it also helps define the kilogram and the Kelvin. But despite the speed of light's reputation as a universal constant, scientists and science-fiction writers alike spend time contemplating faster-than-light travel. So far, no one's been able to figure out how to travel at such speed. But that hasn't slowed our collective hurtle towards new stories, new inventions and new realms of physics

A light year is the distance light can travel in one year – about 10 trillion kilometres (6 trillion miles). It's one way astronomers and physicists measure immense distances across our universe. Light travels from the Moon to our eyes in about one second, which means the Moon is about one light second away. Sunlight takes about eight minutes to reach our eyes, so the Sun is about eight light minutes away. Light from Alpha Centauri, the nearest star system to our own, requires roughly 4.3 years to get here, so Alpha Centauri is 4.3 light years away.

> "THE SPEED OF LIGHT IS SO IMMUTABLE THAT IT IS USED TO DEFINE INTERNATIONAL STANDARD MEASUREMENTS LIKE THE METRE"

Stars and other objects beyond our Solar System lie anywhere from a few light years to a few billion light years away. When astronomers study objects that are far away, the objects appear as they existed at the time the light left them. This principle allows astronomers to see the universe as it looked after the Big Bang, about 13.8 billion years ago. Objects that are 10 billion light years away appear to astronomers as they looked 10 billion years ago, rather than how they appear today.

As early as the 5th century CE, Greek philosophers like Empedocles and Aristotle disagreed on the nature of light speed. Empedocles thought that light, whatever it was made of, must travel, and must have a rate of travel. Aristotle wrote a rebuttal of Empedocles' view in his own treatise, *Sense and Sensibilia*, arguing that light, unlike sound and smell, is instantaneous. Aristotle was wrong, but it would take hundreds of years for anyone to prove it.

In the mid-1600s, Italian astronomer Galileo Galilei stood two people on hills less than a mile apart. Each person held a shielded lantern. One uncovered their lantern; when the other person saw the flash, they uncovered theirs. But Galileo's experimental distance wasn't far enough for his participants to record the speed of light. He could only conclude that light travelled at least ten times faster than sound.

In the 1670s, Danish astronomer Ole Rømer tried to create a reliable timetable for sailors at sea, and accidentally came up with a new best estimate for the speed of light. To create an astronomical clock, he recorded the precise timing of eclipses of Jupiter's moon Io from Earth. Over time, Rømer observed that Io's

$E=MC^2$ EINSTEIN'S EQUATION EXPLAINED

Einstein's investigation of the way that mass increases as an object attempts to accelerate near the speed of light revealed this simple but elegant equation that lies at the heart of all modern physics. Here, E is a body's energy content, m its mass and c the speed of light, a universal constant. It can be used to compare a body's rest mass and energy – excluding energy due to motion – or its total relativistic mass and energy, including energy due to motion.

The idea that mass and energy are interchangeable in extreme circumstances lies at the heart of modern physics. It explains the power source for all stars, where nuclear fusion of light elements into heavier ones converts a small excess of mass directly into energy, and the origin of matter in the universe itself, where enormous amounts of energy released in the Big Bang coalesced into subatomic particles, which then went on to form atoms.

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"MICHELSON'S RESULT WAS ACCEPTED AS THE MOST ACCURATE MEASUREMENT OF THE SPEED OF LIGHT FOR 40 YEARS, UNTIL MICHELSON REMEASURED IT HIMSELF"

MASS INCREASES WITH SPEED

Setting the speed of light as a universal speed limit led Einstein to his remarkable discovery that mass and energy are equivalent. He arrived at this by considering what would happen if an object travelling at relativistic speed continued to pour energy into acceleration. The energy could be provided internally, for instance on a rocket powered by an ion engine, or externally, for example in a particle accelerator.

Einstein realised that in either case the object's kinetic energy would have to increase even if its velocity could not. Since kinetic energy is reliant on both mass and velocity, this indicated that adding energy to an object moving at near-light speed tends to increase its mass. In fact, Einstein found that the energy content of an object is equal to its mass times the speed of light, or c, squared.

Above: The Hubble Space Telescope captured this image of the spiral galaxy NGC 3972, located 65 million light years from Earth in the constellation of Ursa Major

eclipses often varied from his calculations. He noticed the eclipses appeared to lag most when Jupiter and Earth were moving away from one another, showed up ahead of time when the planets were approaching and occurred on schedule when the planets were at their closest or farthest points. In a leap of intuition, he determined that light was taking measurable time to travel from Io to Earth. Rømer's calculations put the speed of light at about 200,000 kilometres (124,000 miles) per second.

In 1728, English physicist James Bradley based a new set of calculations on the change in the apparent position of the stars due to Earth's travels around the Sun. He estimated the speed of light at 301,000 kilometres (185,000 miles) per second – accurate to within about one per cent of the real value. Two new attempts in the mid-1800s brought the problem back to Earth. French physicist Hippolyte Fizeau set a beam of light on a rapidly rotating toothed wheel, with a mirror set up eight kilometres (five miles) away to reflect it back to its source. Varying the speed of the wheel allowed Fizeau to calculate how long it took for the light to travel to the adjacent mirror and back. Another French physicist, Leon Foucault, used a rotating mirror rather than a wheel to perform essentially the same experiment. The two independent methods each came within about 1,609 kilometres (1,000 miles) per second of the speed of light.

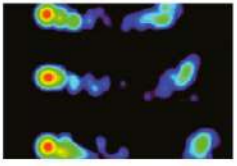
Another scientist who tackled the speed of light mystery was Poland-born Albert A. Michelson. In 1879 he attempted to replicate Foucault's method of determining the speed of light, but Michelson increased the distance between mirrors and used extremely high-quality mirrors and lenses. Michelson's result of 299,910 kilometres (186,355 miles) per second was accepted as the most accurate measurement of the speed of light for 40 years, until Michelson remeasured it himself.

In his second round of experiments, Michelson flashed lights between two mountaintops with carefully measured distances to get a more precise estimate. In his third attempt, just before his death in 1931, he built a 1.6-kilometre (one-mile) depressurised tube of corrugated steel. The pipe simulated a near-vacuum that would remove any effect of air on light speed for an even finer measurement, just slightly lower than the accepted value of the speed of light today. Michelson also studied the nature of light itself. The best minds in physics at the time of Michelson's experiments were divided: was light a wave or a particle?

Michelson, along with his colleague Edward Morley, worked under the assumption that light moved as a wave, just like sound. And just as

FOUR THINGS THAT BREAK THE SPEED LIMIT OF THE UNIVERSE

Einstein predicted that nothing with mass could move faster than light, but there are objects disobeying the laws of physics



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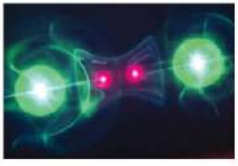

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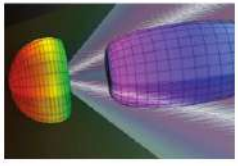

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Source: Wiki Comons © Argonne National Laboratory

SUPERLUMINAL MOTION

Black holes spit out high-speed jets of particles that appear to travel faster than light. This 'superluminal' motion is an optical illusion that occurs when jets moving close to light speed are pointing roughly in our direction. Because the radiation emitted at points along the jet's path isn't moving much faster than the jet itself, the light is compressed – light emitted at different points over the course of a century reaches Earth in just a few years, creating the impression of faster-than-light motion.

ENTANGLEMENT

In quantum physics, particles with entangled properties remain connected by a strange link however widely they are separated. Measuring and 'resolving' the properties of one causes the other to instantaneously resolve itself in the other direction, with no time needed for a message to travel between them. Einstein called this effect 'spooky action at a distance' – the laws of physics seem to permit it because it can't be used to send information at faster-than-light speeds.

A TACHYONIC UNIVERSE

Even if no particles with mass can travel at the speed of light itself, some physicists have pondered whether there could be a whole universe of particles that travel faster than light. Such particles, known as tachyons, would exhibit a variety of strange properties. For example, their energy would decrease as their speed increased. However, attempts to detect evidence of this strange mirror universe have so far proved unsuccessful.

CHERENKOV RADIATION

An often overlooked point is that the universe's ultimate speed limit is the speed of light in a vacuum. When light passes through transparent materials, it can slow down significantly, and sometimes particles moving through the same medium can break this artificially lowered light-speed barrier. The result is a burst of bluish-coloured Cherenkov radiation – the light equivalent of a 'sonic boom' – which can be used to detect high-speed particles such as elusive neutrinos.

© NASA, ESA

sound needs particles to move, Michelson, Morley and other physicists of the time reasoned light must have some kind of medium to move through. This invisible, undetectable stuff was dubbed the 'luminiferous aether'. Though Michelson and Morley built a sophisticated interferometer – a very basic version of the instrument used today at Laser Interferometer Gravitational-Wave Observatory (LIGO) facilities – Michelson couldn't find evidence of any kind of luminiferous aether whatsoever. Light, he determined, can and does travel through a vacuum. "The experiment – and Michelson's body of work – was so revolutionary that he became the only person in history to have won a Nobel Prize for a very precise non-discovery of anything," astrophysicist Ethan Siegal wrote. "The experiment itself may have been a complete failure, but what we learned from it was a greater boon to humanity and our understanding of the universe than any success would've been."

Einstein's theory of special relativity unified energy, matter and the speed of light in a famous equation: $E=mc^2$. The equation describes the relationship between mass and energy. Small amounts of mass (m) contain, or are made up of, an inherently enormous amount of energy (E). Because energy is equal to mass times the speed of light squared, the speed of light serves as a conversion factor, explaining exactly how much energy must be within matter. And because the speed of light is such a huge number, even small amounts of mass must equate to vast quantities of energy.

In order to accurately describe the universe, Einstein's elegant equation requires the speed of light to be a constant. He asserted that light moved through a vacuum, not any kind of luminiferous aether, and in such a way that it moved at the same speed no matter the speed of the observer.

DID YOU KNOW?

Travelling at the speed of light, you could whiz around the Earth 7.5 times in one second.

If we base our understanding of physics on special relativity, the speed of light is the immutable speed limit of our universe – the fastest anything can travel.

Although the speed of light is often referred to as the universe's speed limit, the universe actually expands even faster. The universe expands at a little more than 68 kilometres (42 miles) per second for each megaparsec of distance from the observer. A megaparsec is 3.26 million light years – a really

Right: Light moves more slowly when travelling through diamond than when moving through air, and it moves through both slower than it can travel in a vacuum

TAP HERE TO PLAY

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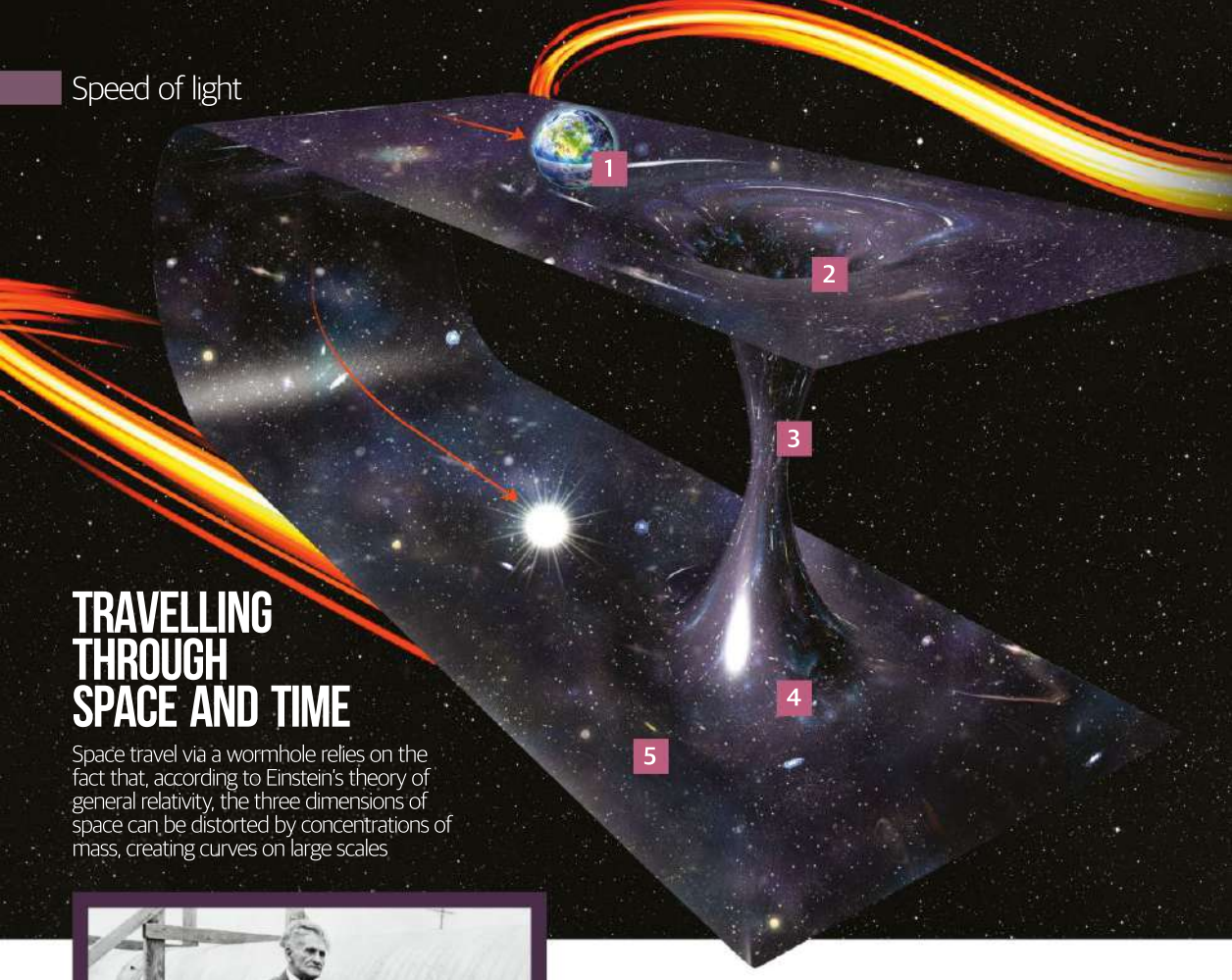
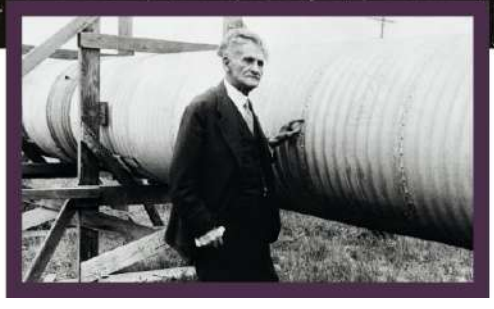


TRAVELLING THROUGH SPACE AND TIME

Space travel via a wormhole relies on the fact that, according to Einstein's theory of general relativity, the three dimensions of space can be distorted by concentrations of mass, creating curves on large scales



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"SPECIAL RELATIVITY DOESN'T CARE ABOUT THE SPEED – SUPERLUMINAL OR OTHERWISE – OF A DISTANT GALAXY. AND NEITHER SHOULD YOU"

PAUL SUTTER

long way. A galaxy one megaparsec away appears to be travelling away from the Milky Way at a speed of 68 kilometres (42 miles) per second, while a galaxy two megaparsecs away recedes at nearly 136 kilometres (86 miles) per second, and so on.

"At some point, at some obscene distance, the speed tips over the scales and exceeds the speed of light, all from the natural, regular expansion of space," says astrophysicist Paul Sutter. "It seems like it should be illegal, doesn't it?" Special relativity provides an absolute speed limit within the universe, according to Sutter, but Einstein's 1915 theory regarding general relativity allows different behaviour when the physics you're examining are no longer 'local'.

"A galaxy on the far side of the universe? That's the domain of general relativity, and general relativity says who cares! That galaxy can have any speed it wants, as long as it stays way far away, and not up next to your face," Sutter says. "Special relativity doesn't care about the speed – superluminal or otherwise – of a distant galaxy. And neither should you."

Light in a vacuum is generally held to travel at an absolute speed, but light travelling through any material can be slowed down. The amount that a material slows down light is called its refractive index. Light bends when coming into contact with particles, which results in a decrease in speed. For example, light travelling through Earth's atmosphere moves almost as fast as light in a vacuum, slowing down by just three ten-thousandths of the speed of light. But light passing through a diamond slows to less than half its typical speed. Even so, it travels through the gem at over 445.8 million kilometres (277 million miles) per hour – enough to make a difference, but still incredibly fast.

Light can be trapped – and even stopped – inside ultracold clouds of atoms, and scientists have even proposed a new way to stop light in its tracks at 'exceptional points' – places where two separate light emissions intersect and merge into one. Researchers have also tried to slow down light even when it's travelling through a

1 LOCAL WORMHOLE
To allow for truly convenient interstellar travel, a wormhole would have to be located (or created) quite close to Earth.

2 DOWN THE FUNNEL
The mouth of a wormhole forms a steep-sided 'gravity well', but there's a safe entrance that avoids crossing the event horizon.

3 THROUGH THE GAP
The passage through the wormhole is 'open', forming a broad cylindrical tunnel so that the crushing gravity of the central singularity can be avoided.

4 NOT-SO-SHORTCUT?
The trip through a wormhole might be shorter, but it's still not instantaneous. Because travelling through a wormhole might still involve near-light speeds, effects such as time dilation would make the journey seem shorter.

5 SAFE PASSAGE
In theory, it's possible to steer a passage that hugs the outer edge of the wormhole to emerge at the other end.

Left: Michelson standing alongside the mile-long vacuum tube which would be used in his last and most accurate measurement of the speed of light

Right: The Alcubierre drive is a hypothetical technology that warps space to achieve faster-than-light travel

vacuum. A team of Scottish scientists successfully slowed down a single photon, or particle of light, even as it moved through a vacuum. In their measurements, the difference between the slowed photon and a 'regular' photon was just a few millionths of a metre, but it demonstrated that light in a vacuum can be slower than the official speed of light.

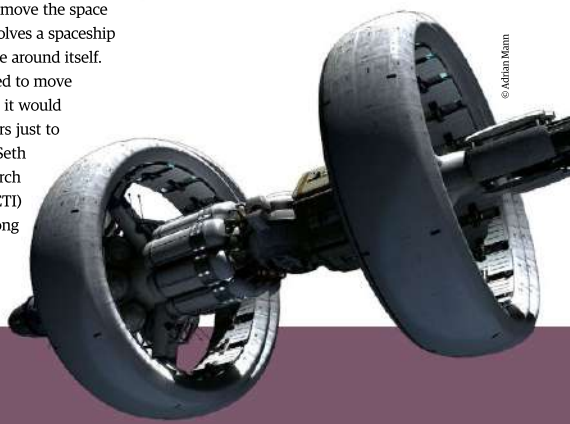
Science fiction loves the idea of 'warp speed'. Faster-than-light travel makes countless sci-fi franchises possible, condensing the vast expanses of space and letting characters pop back and forth between star systems with ease. But while faster-than-light travel isn't guaranteed impossible, we'd need to harness some pretty exotic physics to make it work. Luckily for sci-fi enthusiasts and theoretical physicists alike, there are lots of avenues to explore. All we have to do is figure out how to not move ourselves – since special relativity would ensure we'd be destroyed before we reached high enough speeds – but instead move the space around us. One proposed idea involves a spaceship that could fold a space-time bubble around itself.

"If Captain Kirk were constrained to move at the speed of our fastest rockets, it would take him a hundred thousand years just to get to the next star system," says Seth Shostak, an astronomer at the Search for Extraterrestrial Intelligence (SETI) Institute. "So science fiction has long postulated a way to beat the speed of light barrier so the story can move a little more quickly." Without faster-than-light travel, any *Star Trek* – or *Star Wars* for that matter – would be impossible. If humanity is ever to reach the farthest – and constantly expanding – corners of our universe, it will be up to future physicists to boldly go where no one has gone before.

HOW LONG IS A JIFFY?
When you say you'll be somewhere in a 'jiffy', you are actually referring to a specific unit of time. For physicists, a jiffy is how long light takes to travel a distance of one femtometre – one quadrillionth of a metre.

Vicky Stein
Science journalist
Vicky holds a degree in science communication and has worked as a reporter for Stanford News Service, Space.com and LiveScience

Daisy Dobrijevic
Staff Writer
Daisy is **All About Space**'s Staff Writer. She previously worked for *BBC Factual* as a researcher and *BBC Sky at Night* magazine as an editorial assistant.



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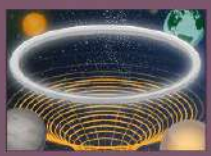
HOW TO BUILD A WORMHOLE

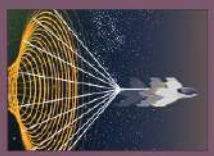
Could we build our own warp gate through space-time?

CREATE NEGATIVE ENERGY
The vital first step towards building a working wormhole would be to understand how to manufacture a source of 'negative energy' on a large scale. Although various forms of negative energy exist, there's no guarantee that a form suitable for building wormholes exists.



FIND A NATURAL WORMHOLE
Wormhole types depend on cosmology and particle physics. Non-traversable ones may link black holes, while microscopic ones may connect entangled quantum particles. An advanced detector would be needed to identify and 'collect' one end of a wormhole to use.

MAKE IT TRAVERSABLE
Adding negative energy would create an anti-gravitational force. In the case of a non-traversable black hole wormhole, this would draw the opening out into accessible space beyond the event horizon, while for a microscopic wormhole it could expand the tunnel to a traversable size.



FIRST TRIP
The first exploration of a newly opened wormhole would be done by a space probe. If it led somewhere safe and useful, the nearby end could be relocated closer to hand by a 'space tug' using the attractive force of gravity or repulsive 'antigravity' from the negative energy source.

x5 Images © Ed Crooks

COSMIC MOTORWAYS
Once a civilisation has learned how to open up one wormhole, it's easy to build a network of cosmic shortcuts. Some suggest they could even be used to build time machines, although the laws of physics mean that such a machine could not allow travel back to a time before it was created.

WHAT DID OUR SUN LOOK LIKE IN ITS INFANCY?

New findings may shed light on what our star looked like in its youth

Reported by Charles Q. Choi

Newborn stars are surrounded by a disc of gas and dust from which planets, asteroids, comets and moons are born. The star's magnetic field connects the star with this protoplanetary disc, "funnelling material from the disc onto the star," said Catherine Espaillat, an astrophysicist at Boston University. In a recent study, Espaillat and her colleagues investigated the spot where a star's magnetic field deposits protoplanetary disc material onto a star. "This footprint is called the 'hotspot' since the material is very hot when it slams onto the surface of the star," she explained. They focused on GM Aurigae, a star about the same mass as the Sun located about 420 light years away in the constellation of Auriga.

GM Aurigae is only about 2 million years old; in comparison, the Sun is about 4.6 billion years old. Previous work could not get a clear picture of the structure and dynamics of these hotspots. But in the new study, the researchers analysed GM Aurigae with multiple space and ground-based observatories. "This is the first time such an extensive time-coordinated study has been done on a young star," Espaillat said.

The scientists found the visible light they detected from GM Aurigae peaked in brightness about a day after ultraviolet light. They suggested this happened because the source of the visible and ultraviolet light moved into and out of view as it rotated along with the star.

When combined with computer models of matter accreting onto stars, these findings suggest the hotspot varies in density from its centre to its rim on the star's surface. Areas of the hotspot with different densities have different temperatures and so emit different wavelengths of light.

"For the first time, we mapped the structure in this hotspot using observations and confirmed theoretical predictions," Espaillat said. "This result teaches us more about what our Sun looked like when it was young. Now our Sun has sunspots, dark areas where the temperature on the surface is cooler. When our Sun was young, it also had hotspots." Future research will analyse GM Aurigae and other stars to detect more details about these hotspots.

> "THIS IS THE FIRST TIME SUCH AN EXTENSIVE TIME-COORDINATED STUDY HAS BEEN DONE ON A YOUNG STAR"
> CATHERINE ESPAILLAT

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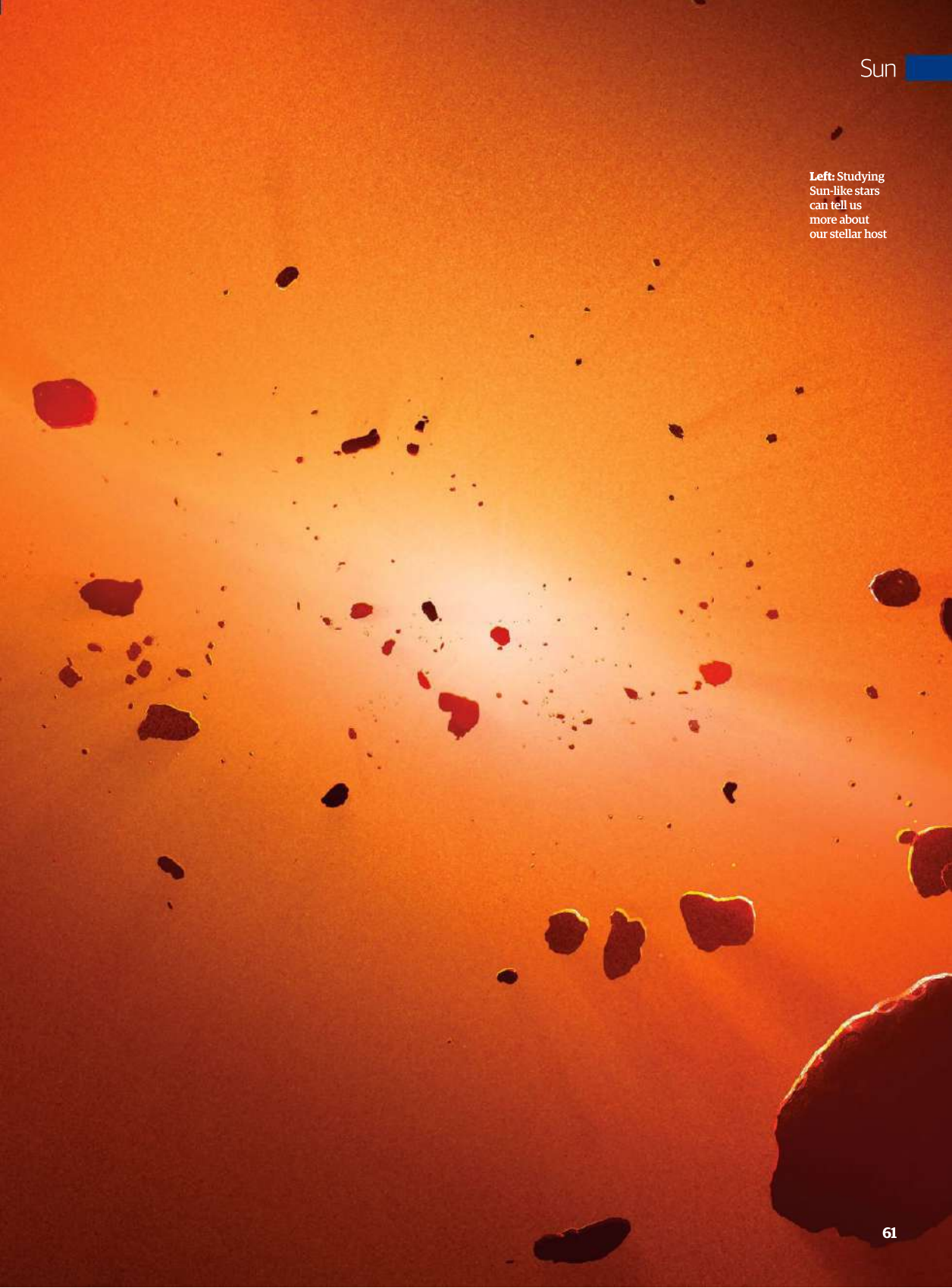


Left: Studying Sun-like stars can tell us more about our stellar host

MYSTERIES OF THE UNIVERSE

WHAT IS CAUSING JUPITER'S ENERGY CRISIS?

The gas giant is much warmer than expected, despite being so far from the Sun. But are scientists closer to discovering why?

Reported by David Crookes

If you were hoping for a warm and inviting holiday on a planet in the Solar System, you'd generally look to avoid Jupiter. After all, it's a long-haul journey at five times the distance from the Sun as Earth, some 778 million kilometres (484 million miles). It also takes 43 minutes for sunlight to travel there; not ideal if you're hoping to lay on a sunlounger and soak up the rays, you would assume. And that's what astronomers thought too. "Jupiter's upper atmosphere should be about -110 degrees Celsius (-166 degrees Fahrenheit) based on the amount of heating imparted to it by sunlight," affirms James O'Donoghue of the Japan Aerospace Exploration Agency (JAXA) Institute of Space and Astronautical Science. But as O'Donoghue and scores of other astronomers know only too well, that isn't the case in reality.

TAP HERE TO PLAY

© NASA/ESA Tobias Roetsch

JUPITER BY NUMBERS

90%
Percentage of hydrogen in the atmosphere

10%
Percentage of helium in the atmosphere

20,000x
Jupiter's magnetic field is more powerful than Earth's

426°C
The temperature within Jupiter's thermosphere

9.9
Time taken, in hours, for the planet to rotate

79
Jupiter has many moons, including volcanic Io

SEVEN
Number of times a spacecraft has visited Jupiter

11
Number of Earths that could fit across Jupiter's equator

FOUR
Number of rings

HEATING JUPITER'S UPPER ATMOSPHERE

How aurorae are thought to be a major source of the gas giant's heat

Instead of the expected chilly upper-atmospheric temperature, Jupiter is hot, burning at a blisteringly hellish 426 degrees Celsius (800 degrees Fahrenheit). It's a temperature near-identical to the surface of Venus, the Solar System's hottest planet, and "hundreds of degrees hotter than sunlight alone can explain," O'Donoghue says. But why is Jupiter so unexpectedly scorching? It's a question that has befuddled astronomers for 50 years, and yet the answer has become a lot clearer of late.

The puzzle of Jupiter's heat began to emerge when it became clear that Jupiter had an upper-atmosphere temperature comparable to the solar minimum found at Earth. Measurements taken over the years have only served to confirm this. "One way of measuring the temperature involved the Galileo probe in 1995, which directly entered the planet and took its temperature continuously – until it burned up when it got very deep," O'Donoghue says.

As such, astronomers have sought to discover the likely source of the planet's thermal boost. They have modelled the upper atmosphere and used observational data – the latter made easier because you don't need to delve too deep to find the heat. "If we take an Earthly example of just how high this heating is, it would almost be like the vacuum of space that astronauts sit in," O'Donoghue explains. "The same is true for the high-altitude temperatures seen at Jupiter – we are so high up that it may as well be space, but this thinness of atmosphere is useful to us because it exhibits great change with small amounts of forcing, making it a neat little sensitive window of conditions very high above Jupiter's cloud tops."

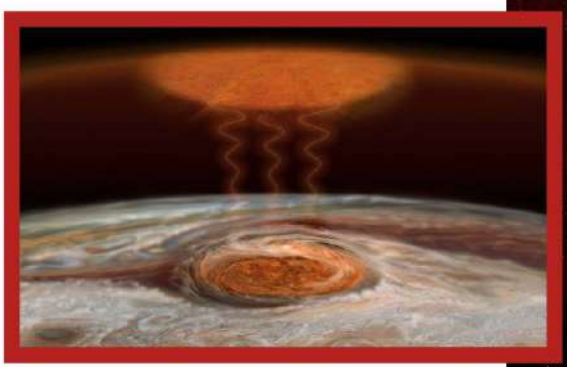
As with others before him, O'Donoghue and his team have been hard at work analysing the heat of Jupiter's upper atmosphere. In doing so they have looked to build on previous studies, such as one in 2016 which saw scientists observe non-visible infrared light above Jupiter's cloud tops using the SpeX spectrometer at NASA's Infrared Telescope Facility on Mauna Kea, Hawaii.

Back then, temperatures were found to be higher in certain latitudes and longitudes, leading to the conclusion that the source of Jupiter's extra heat could be the planet's Great Red Spot – there was a spike in temperature directly above it.

O'Donoghue was part of that study when he was a researcher at Boston University's Center for Space Physics, and he still thinks that it contributes to the heating. But he also believes there is another major reason why the upper atmosphere of Jupiter is warmer than it should be, thanks to a more recent study of supplementary data.

"For our latest work, we've measured longitude and latitude temperatures by seeing what temperature a special type of hydrogen is all over the planet," he says. It's this work which has perhaps made the biggest breakthrough, with the suggestion that Jupiter's so-called 'energy crisis' is actually due to the gas giant's intense aurorae.

Such a theory – that aurorae may be the major source of Jupiter's energy – isn't entirely new. "Heating the whole planet with an aurora has



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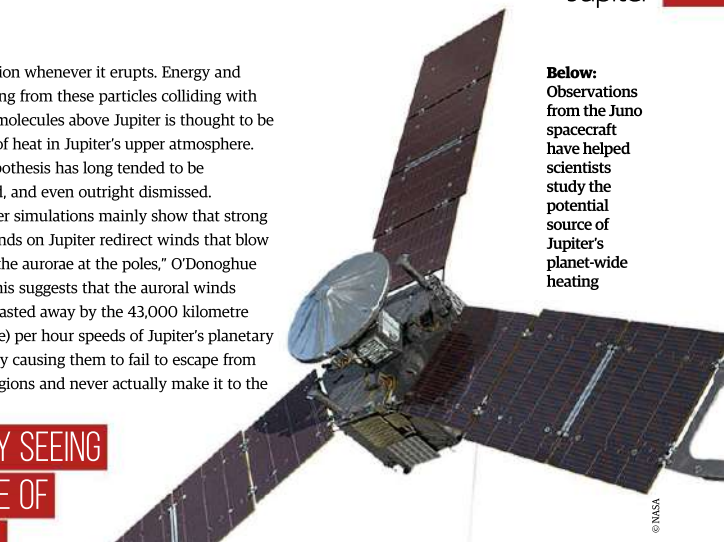
Right: The Great Red Spot produces gravity waves and audio waves, which are also thought to heat the upper atmosphere of Jupiter

long been thought to be a candidate for the high temperature," O'Donoghue affirms. And that seems to make sense. Aurorae do occur on Jupiter, a planet that has a strong magnetic field like Earth.

Produced by electrically charged particles interacting with a planet's atmosphere, they result in energy and light. On Earth we see them as displays of the northern lights and southern lights, and they are caused by charged particles from the Sun being accelerated by Earth's magnetic field, colliding with atoms and molecules as they travel towards the poles.

On Jupiter the charged particles come from its volcanic moon Io, which sends a lot of material into the region whenever it erupts. Energy and light resulting from these particles colliding with atoms and molecules above Jupiter is thought to be the source of heat in Jupiter's upper atmosphere. Yet this hypothesis has long tended to be downplayed, and even outright dismissed.

"Computer simulations mainly show that strong westerly winds on Jupiter redirect winds that blow away from the aurorae at the poles," O'Donoghue explains. This suggests that the auroral winds are being blasted away by the 43,000 kilometre (27,000 mile) per hour speeds of Jupiter's planetary spin, thereby causing them to fail to escape from the polar regions and never actually make it to the



Below: Observations from the Juno spacecraft have helped scientists study the potential source of Jupiter's planet-wide heating

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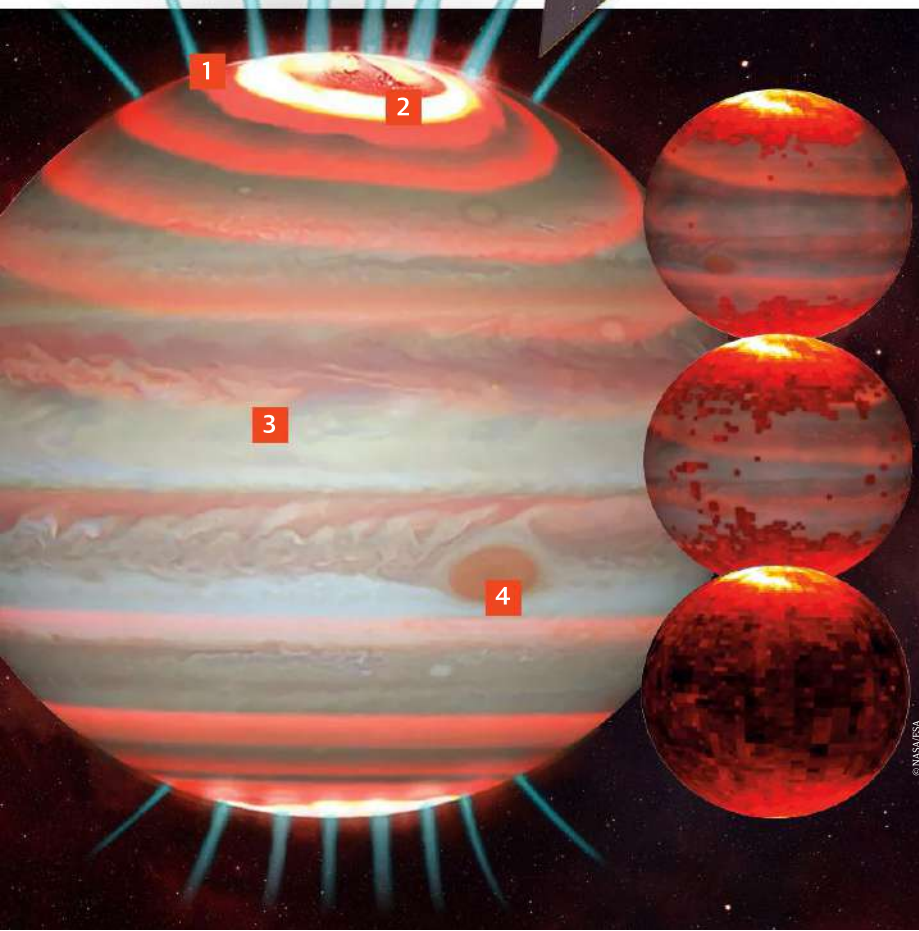
"WE'VE MEASURED TEMPERATURES BY SEEING WHAT TEMPERATURE A SPECIAL TYPE OF HYDROGEN IS ALL OVER THE PLANET"

JAMES O'DONOGHUE



TEMP (°C)

700
600
500
400
300
200

1 JUPITER'S MAGNETIC FIELD LINES

Jupiter has a strong magnetic field. Electrically charged material ejected from Io's eruptions is accelerated to the north and south poles of Jupiter.

2 SCORCHING AURORAE

When the particles strike atoms and molecules in Jupiter's atmosphere, energy and light are released. This sets off aurorae and causes intense heating over the polar regions.

3 CARRYING THE HEAT

Global winds carry the heat towards the equator, warming the upper atmosphere as they do so and leading to a widespread heating of the planet.

4 THE RED HOTSPOT

The Great Red Spot is a massive Jovian storm, and temperatures there are about 1,330 degrees Celsius (2,420 degrees Fahrenheit) – higher than the general atmospheric temperatures elsewhere.

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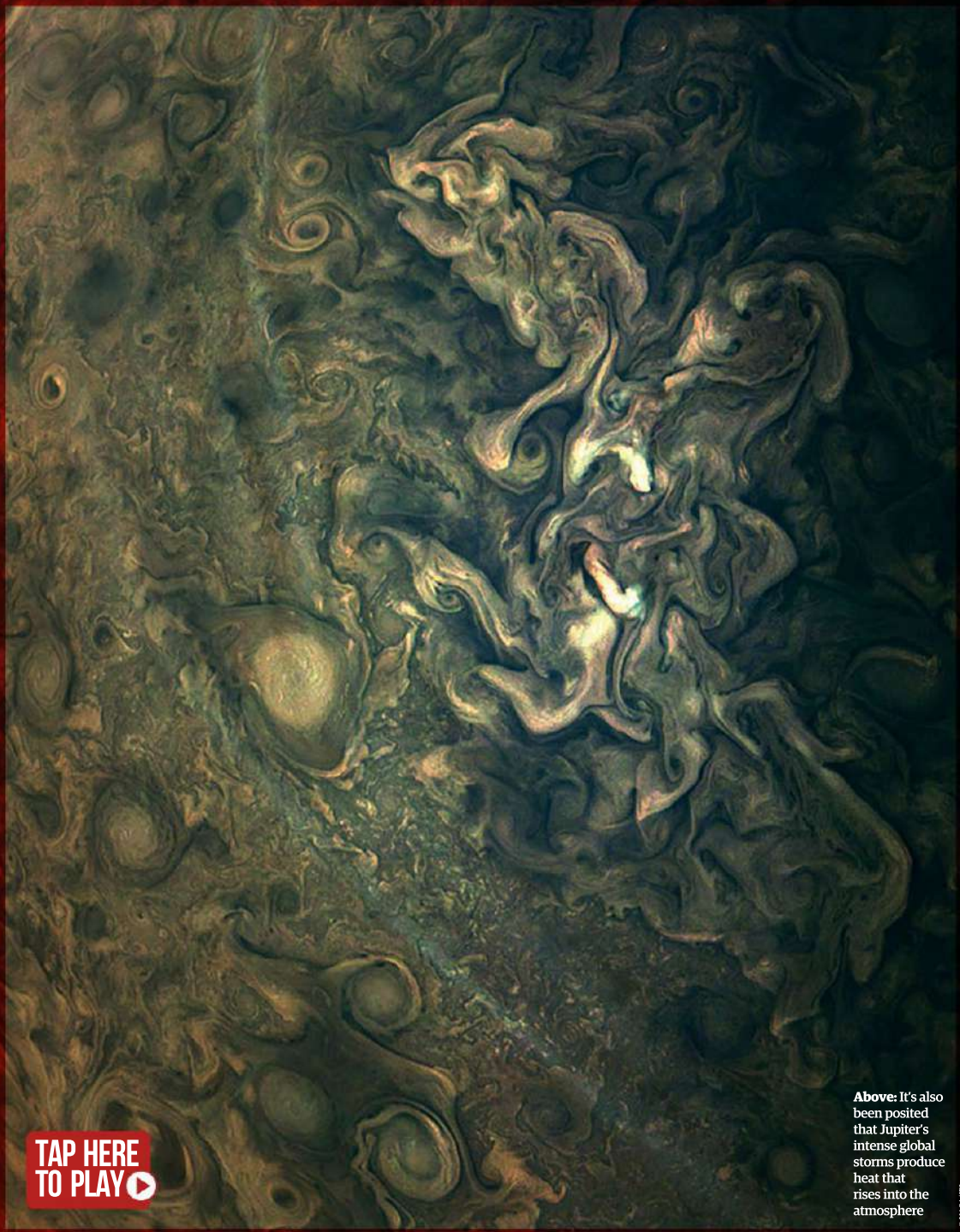

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Above: It's also been posited that Jupiter's intense global storms produce heat that rises into the atmosphere

© NASA/JPL

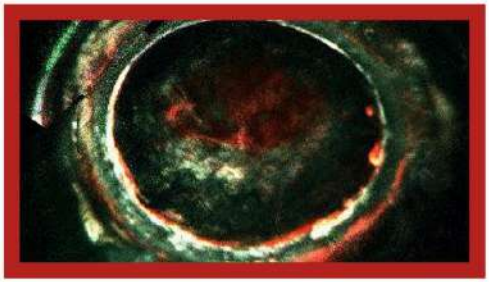
equator. If this was the case, the aurorae wouldn't be able to heat the whole atmosphere.

"Given these difficulties, other theories have been proposed, such as heating from below by gravity, and sound waves which dump energy in the upper atmosphere, crashing like waves on a beach," O'Donoghue says. "We still think acoustic waves or gravity waves may provide additional heating, just in a more localised way above storms, and we may need to zoom in even more to see storms heating the atmosphere above them. Overall, though, we are confident that auroral heating is the major source of heating globally."

Based on observations, O'Donoghue and his team are suggesting the westward winds may not be as strong as the equatorial winds. They're saying the auroral winds do escape from the polar regions, do find their way to the equator and so do heat up the atmosphere. Given the evidence used to reach the conclusion, it offers the most plausible explanation for Jupiter's mysterious energy.

"We knew from individual single-point measurements over the years that the planet was far too hot, but we didn't have a reliable global map of temperatures to see where the heat was coming from," says O'Donoghue of the motivation to start the study. Thankfully, the researchers were able to resolve the situation primarily using data from the W. M. Keck Observatory, located on Mauna Kea in Hawaii. But what did they do?

To begin with, the team monitored data from the Keck Observatory. They used the near-infrared spectrograph on the Keck II telescope for five hours on both 14 April 2016 and 25 January 2017. This enabled the team to trace heat from electrically charged hydrogen molecules in Jupiter's atmosphere as they headed from the gas giant's magnetic poles towards the equator.



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Above: Taken by Juno's Ultraviolet Imaging Spectrometer, this image shows electrons being accelerated towards the atmosphere, aligned to the magnetic fields

Below: The Keck II telescope was used to observe Jupiter for ten hours, spread across two nights

They then began amassing more measurements to produce a global temperature map of Jupiter. "It's a simple idea in principle," O'Donoghue continues. "But low latitudes are nearly 100 times fainter than the aurorae, so it's difficult to get a reliable map of temperatures."

To ensure they were working with images of a sufficiently high resolution, the astronomers continued to work with Keck II, using it to take more temperature measurements. Only measurements with uncertainty in the recorded value of less than five per cent were used, and eventually the team was able to work with more than 10,000 data points.

"Using the largest and best equipment in the world to produce the temperature maps, we managed to get the resolution required to show that the aurorae are the major source of global heating," he says. The high-resolution mapping showed that heat in the upper atmosphere was widely distributed rather than trapped around the poles. Given there is only a slight decrease in heat at the equator, it's compelling evidence of aurorae being the origin of the extra heat.

Rather than relying on data from Keck II alone, though, the team also drew supplementary

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THREE POTENTIAL EXPLANATIONS

What's making Jupiter hotter than expected?

THE SUN'S RAYS ARE INCREDIBLY INTENSE

This explanation can be immediately dismissed. The Sun's rays alone should cause the upper atmosphere of Jupiter to be about -110 degrees Celsius (-166 degrees Fahrenheit), so the fact that it's much hotter than that based on simulations points to another heat source – the whole point of the ongoing studies.

© NASA

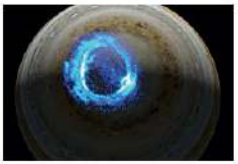
ACTIVE STORMS CAUSE WARMING WAVES

The temperature over Jupiter's Great Red Spot is about 1,300 degrees Celsius (2,400 degrees Fahrenheit) and it's entirely possible that active storms are heating the planet's atmosphere. Turbulence above this area could be creating sound waves that heat the air. This warming effect is likely to be localised, however.

© NASA/JPL

AURORAE GIVE A THERMAL BOOST

The findings of the latest study show that intense aurorae are most likely responsible for the warming of Jupiter's entire upper atmosphere. Observations show that westward winds do not prevent aurorae escaping the polar regions. Instead they head towards the equator and cause widespread warmth.



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magnetic field information from NASA's Juno spacecraft using a near-infrared spectrograph. Built by Lockheed Martin and operated by NASA's Jet Propulsion Laboratory (JPL), the probe, which entered the orbit of Jupiter on 5 July 2016 and has been monitoring it ever since, has enabled scientists to track the planet's atmospheric heating in the greatest of detail.

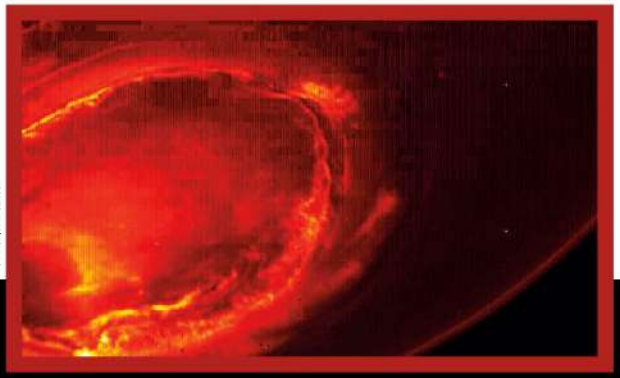
"The Juno spacecraft provided high-resolution information on what the magnetic field looked like," says O'Donoghue of the probe that has been constantly dipping below the dense cloud cover and the intense radiation field for a closer look at the gas giant.

Yet that is not all. "The Hisaki spacecraft data has helped to demonstrate previously that the solar wind is able to affect Jupiter's aurorae, which is something many people would otherwise doubt is possible," says O'Donoghue. This means that a stream of high-energy particles coming from the Sun is being carried on its own magnetic field, putting pressure on Jupiter's planetary field and enhancing the aurorae.

Scientists even captured the enhanced aurorae, seeing a potential heat-shedding event for themselves. "I think the temperature map on its own shows that the aurorae heat the planet, but on top of that we have this exciting heating event. It was really an unexpected bonus, showing that if you dump a load of energy into the aurora, you see it moves towards the equator as well," O'Donoghue explains. "We plan to try and catch something like this again, but it can only really happen one or two times in a month."

But why is this so important, and what can it tell us about other planets? Jupiter isn't actually alone in its 'energy crisis'. The upper atmospheres of Saturn, Uranus and Neptune are also thought to be hotter than expected too. Data gathered by the Cassini spacecraft produced a global map of Saturn's upper atmosphere, and showed that it too was being heated by electrical currents created at its poles. And aurorae are the likeliest explanation once again.

The plan now is to continue analysing the data, produce more maps and track another auroral event in action. "For decades we haven't known what is causing global heating," says O'Donoghue. "It was challenging our understanding of basic physics not only at Jupiter, but also at any giant planet like Saturn, Uranus and Neptune, or even exoplanets. While it was thought that heating by the aurorae of the entire planetary upper atmosphere could happen, our findings now show definitively that it does happen."



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Left: Infrared image of the southern aurorae of Jupiter, taken by the Juno orbiter in 2016

Below: Hubble captured aurorae on Jupiter in 2016

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

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ASTROPHYSICS

Can a black hole disappear?

Surprisingly, yes, a black hole could disappear. It would take a very long time though. Black holes are regions of space which have so much mass in such a small volume that the escape velocity – the speed you need to go to escape the gravitational pull of the body – becomes greater than the speed of light. These cosmic behemoths can also grow in mass as material falls onto them. If a black hole finds itself in a quiet region of the universe, however, the strange world of quantum mechanics and the extreme gravity of the black hole cause a phenomenon named Hawking radiation, one of the discoveries of the late Stephen Hawking.

In quantum mechanics, space is full of entangled 'virtual' particle pairs, which spring into existence from quantum fluctuations and just as rapidly disappear again. When this happens right at the event horizon of a black hole, there is a chance that one of these particles falls into the black hole, while the other escapes. Without its virtual 'partner' the escaping particle cannot disappear again – to conserve mass and energy the black hole thus loses mass. This process is very unlikely, so this evaporation is very slow. A black hole the mass of our Sun would take 10^{67} years to evaporate. Given that our entire universe is currently approximately 13.8 billion years old, this isn't something we have to worry about for a while.

Dr Timothy Davis, senior lecturer, Cardiff University

Below: Black holes evaporate in a phenomenon known as Hawking radiation

© Tobias Roetsch

Above: Spacecraft are monitored carefully to keep them on track

© Adrian Mann

Did you know?

Hawking discovered that even non-rotating black holes emit radiation.

SPACE EXPLORATION

How do you navigate a spacecraft?

For a spacecraft, determining the location and heading requires a radio link from the spacecraft to ground stations. This tells us the current distance because we can see the signal travel time. We also see the Doppler shift, a change in the received frequency depending on the speed at which the spacecraft travels towards or away from Earth.

We need a lot of measurements that cover a time span of days or weeks. Then a very complex, repetitive mathematical procedure on a computer finds out one set of orbital elements at a given time, which reproduces the set of measurements obtained. In theory, once the orbital state is known, the state can be computed at any later time. But in practice this does not work out, because the state is never known perfectly. Also, the orbit is perturbed by factors that we don't know. Our prediction and the actual orbit will drift apart, and the above process must be repeated regularly. Getting to the target requires correction manoeuvres using small rocket engines on the spacecraft. These manoeuvres can be computed and applied every time the orbital state has been updated.

Michael Khan, European Space Operations Centre, Germany

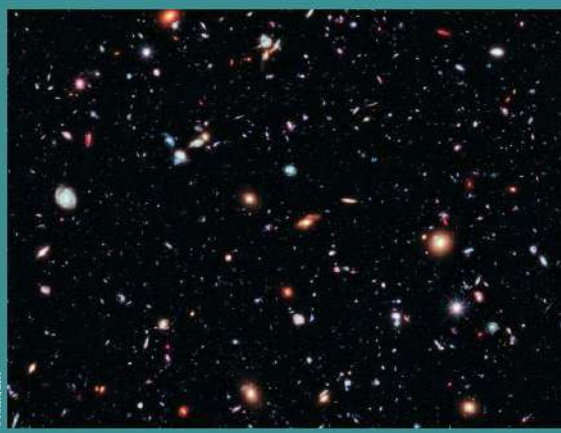
COSMOLOGY

What can gravitational waves tell us about the early universe?

Gravitational waves might be able to shed light on some of the most intriguing mysteries of our universe, helping us to understand what happened during the very first moments of its lifetime. Contrary to what happens with light, gravitational waves can reach us from the first moments of the universe's history, due to the weakness of the gravitational force. Thus gravitational waves provide a unique tool to investigate the early universe. If gravitational waves from the early universe were detected, they would deliver extraordinary information about what happened right after the beginning of time, at energies that cannot be explored with particle colliders.

Many possible cataclysmic phenomena could produce gravitational waves in the early universe. Preheating, for instance, can be thought of as a series of explosions that occurred right after inflation. Phase transitions are phenomena in which the universe changes its state, analogous to boiling water that gets converted into water vapour. Other phenomena involve the formation of primordial black holes and axions, both of which might explain the nature of dark matter. In conclusion, the detection of gravitational waves from the early universe would enlighten us about the mysterious first moments of the universe's history.

Dr Francesco Muia, postdoctoral researcher, Stephen Hawking fellow, University of Cambridge

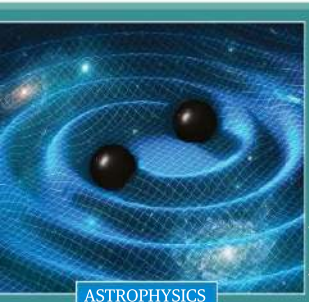


Right: Hubble's deep-field images reveal some of the oldest galaxies in the universe

© NASA/ESA

"GRAVITATIONAL WAVES CAN REACH US FROM THE FIRST MOMENTS OF THE UNIVERSE'S HISTORY"

DR FRANCESCO MUIA



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ASTROPHYSICS

How do gravitational waves work?

Through our understanding of general relativity, we know that gravity can make gravitational waves, ripples in the fabric of space-time. The realisation that gravitational waves exist came from a simplified form of general relativity, and Einstein didn't know if the waves were real or just an artefact of the simplification process. It took several decades before physicists came to the firm conclusion that general relativity does support gravitational waves.

Pretty much anything in the universe doing anything at all makes gravitational waves. All it takes is a little wiggling, which gravitational waves have in common with pretty much any other wave – if you wiggle around in water, you make water waves. If your voice box wiggles around, it makes sound waves. If you wiggle an electron, you make electromagnetic waves. To make a gravitational wave, all you need to do is make mass accelerate. These waves travel out from the source at the speed of light and are literal ripples in gravity. When a gravitational wave passes through you, you get stretched and squeezed as if you were a piece of putty.

Dr Paul Sutter, SUNY Stony Brook and the Flatiron Institute

PLANETS

How do you study the core of a planet?

On Earth, seismic waves were used to measure the core's radius. The InSight mission has recently used seismic shear waves reflected from the surface of the core to estimate Mars' core radius. These methods require a lander which is equipped with a sensitive seismometer, and suitable seismic sources. Similar techniques have been used to measure the small lunar core, where both moonquakes and surface impacts were detected. A future seismic mission to the Saturnian moon Titan is planned by NASA.

In the absence of a seismometer, careful estimates of the rotational and gravitational properties of a planet, like those made for Mercury by MESSENGER, can be used to infer properties of the core. Recent observations of vibrations in Saturn's rings have been used with gravitational measurements to learn about the properties of its huge ice-rock core. Finally, examination of planetary magnetic fields provides important information about the temperature and heat flow inside the cores of some planets within our Solar System.

Dr Jessica Irving, senior lecturer, School of Earth Sciences, University of Bristol

SPACE EXPLORATION

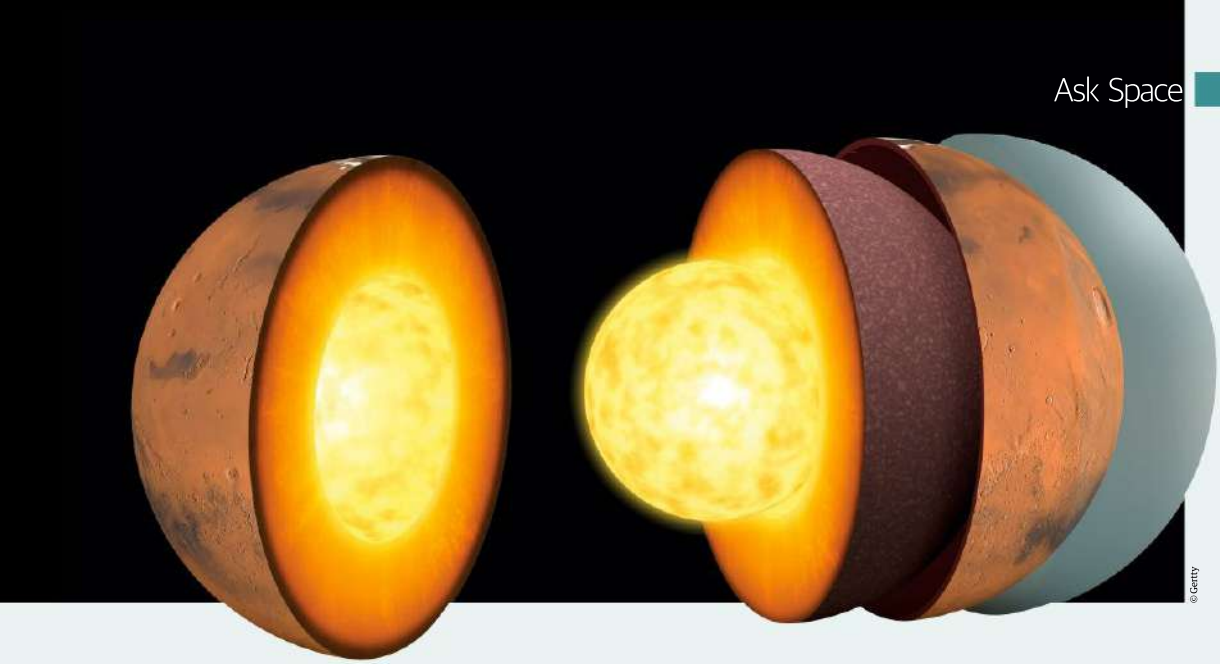
Why is exploring lava tubes on the Moon so important?

Below: Lunar lava tubes could serve as pre-shielded bases

My belief is that in the future you will have to live on the Moon. There will be some settlements on the Moon – or as we call it, 'Moon Village – maybe by 2035 or around that time frame. You will have to build some structures for people to live in, and it will take a tremendous amount of energy and resources to build something like that. But if you have a lava tube, you already have an environment that is shielded from radiation and many other things. You are getting an environment where you can already store stuff; you can live and work there.

Robots and humans will be working alongside each other on the Moon, and I believe that exploring lava tubes is very important for future settlements. From a scientific perspective it's a very interesting environment that has been left alone for billions of years. For billions of years there has been no sunlight, for billions of years there has been no lunar dust. The lava tubes have been shielded from all those externalities, which is not the case here on Earth. This means it's a very good potential site for science and to learn more about the universe.

Pavlo Tanasyuk, founder and CEO of space start-up Spacebit



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Did you know?

Using lava tubes would save the cost of transporting as many radiation-proof materials to the Moon.

© ESA

Above: Several indirect methods can give clues about core size

Right: Though it looks like a normal red star, its core tells another story

STARS

What are Thorne-Żytkow objects?

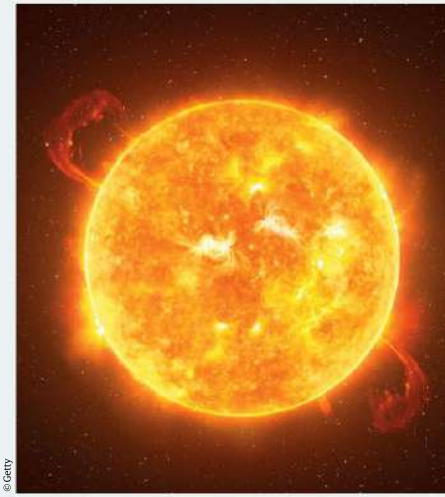
To the untrained eye, Thorne-Żytkow objects, or TŻOs, are unassuming red supergiants. Except they harbour a dark secret inside: instead of an element-forging furnace in their cores, there lies a stellar corpse called a neutron star. In other terms, a TŻO is nothing more than a dead star masquerading as a living one.

There are many ways nature can create this strange combination. Some astronomers speculate a red supergiant could capture a neutron star travelling close by. Others posit that a single star's innermost layers could collapse in on themselves, form a neutron star, but maintain a red supergiant appearance on the outside. So far these stars are theoretical; we've found a few candidates proving they exist – the most famous, HV 2112, is located 60 kiloparsecs from Earth. Astronomers find proof by using spectroscopy. A TŻO would have an odd mixture of elements melded on the hot, dense surface of the inner neutron star that would not exist in a true red supergiant. Moreover, we can also use gravitational waves to make observations. If we search for gravitational waves from a suspected TŻO, we would 'see' straight through its red supergiant mask and reveal the neutron star underneath!

Lindsay DeMarchi, PhD researcher, Northwestern University

"INSTEAD OF AN ELEMENT-FORGING FURNACE IN THEIR CORES, THERE LIES A STELLAR CORPSE CALLED A NEUTRON STAR"

LINDSAY DEMARCHI



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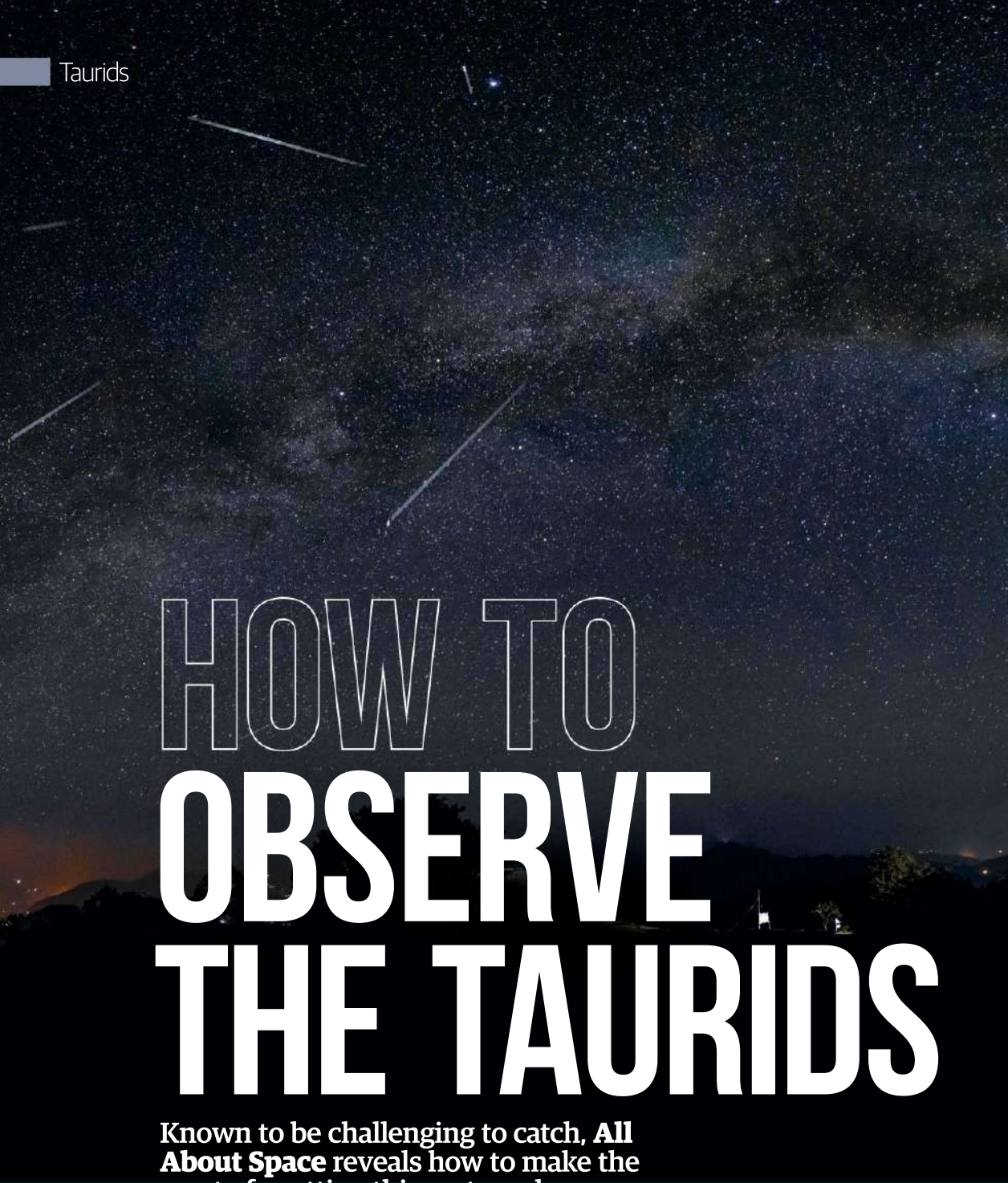


HOW TO OBSERVE THE TAURIDS

Known to be challenging to catch, All About Space reveals how to make the most of spotting this meteor shower

© Alamy

Written by Stuart Atkinson and Daisy Dobrijevic

COMET 2P/ENCKE

Radiant constellation: Taurus

Peak activity: Southern Taurids on 10 October and Northern Taurids on 12 November

Peak meteor count: approximately five per hour

© NASA

Inset: NASA's MESSENGER spacecraft captured this image of Comet 2P/Encke during the comet's closest approach to Mercury in 2013

The Taurid meteor shower is a long-lasting annual meteor shower that occurs every year from late October and through November and is visible in both the Northern and Southern Hemispheres. The shower gets its name from the constellation Taurus, from which the meteors appear to radiate. Meteor showers occur when Earth passes through a stream of space dust left behind by a comet. In the Taurids' case that comet is 2P/Encke, a 2.4-kilometre (1.5-mile) wide chunk of ice and dust that orbits the Sun every 3.3 years – the shortest known orbital period for a comet.

The comet was first spotted by French astronomer Pierre Méchain in 1786, and was first recognised as a periodic comet in 1819 when Johann Franz Encke – from who the comet gets its name – calculated its orbit. Every time Comet 2P/Encke rounds the Sun it leaves fresh dust behind it, and if Earth passes through a particularly dense streamer or trail, we get to see more meteor activity than usual. This happened in 2008 and 2015, suggesting a seven-year cycle of enhanced activity. This pattern suggests that next year, 2022, will be the next 'enhanced' Taurid show, but it will definitely be worth looking at this year, too.

The comet stream that causes the Taurids is so dispersed it takes Earth a relatively long time to pass through. We therefore experience two separate segments of the shower: the Southern Taurids are visible from 10 September to 20 November, and the Northern Taurids are visible from 20 October to 10 December.

The two showers are an earmark of what eventually happens to an elderly meteor swarm. Even at the very beginning of the swarm's development, the associated particles couldn't have been moving in precisely the same orbit as the parent comet; this slight divergence slowly accumulates with time. And the Sun is not the only body gravitationally controlling the particles' orbits – the planets are having subtle

UPCOMING METEOR SHOWERS

LEONID METEOR SHOWER
Active: 6 to 30 November
Peak: 17 November
Zenith Hourly Rate (ZHR): 15

ALPHA MONOCEROTID METEOR SHOWER
Active: 15 to 25 November
Peak: 21 November
Zenith Hourly Rate (ZHR): Variable

NOVEMBER ORIONID METEOR SHOWER
Active: 13 November to 6 December
Peak: 28 November
Zenith Hourly Rate (ZHR): 3

PHEONICID METEOR SHOWER
Active: 28 November to 9 December
Peak: 2 December
Zenith Hourly Rate (ZHR): Variable

PHI CASSIOPEID METEOR SHOWER
Active: 1 to 8 December
Peak: 6 December
Zenith Hourly Rate (ZHR): Variable

PUPPID-VELID METEOR SHOWER
Active: 1 to 15 December
Peak: 7 December
Zenith Hourly Rate (ZHR): 10

effects on the stream as well. Since the positions of the planets are constantly changing, the particles pass nearer to them on some of their revolutions around the Sun, thereby redirecting parts of the stream, fanning it out and splitting it. What was originally one stream diffused into a cloud of minor streams, and isolated particles put on a rather modest show.

At peak viewing times you may be able to see about half a dozen shooting stars per hour. Compared to other meteor showers, the Taurids move relatively slowly, travelling across the sky at about 27 kilometres (17 miles) per second. The Perseids travel twice as fast, averaging 58 kilometres (36 miles) per second. A typical meteor is produced when a piece of space dust - perhaps the size of a coffee grain - burns up in Earth's atmosphere, and it zips across the sky so quickly it's gone in the blink of an eye. Fireballs are produced when larger objects, the size of a peanut or a grape, or even larger, plunge through the atmosphere.

Fireballs travel much more slowly than normal meteors, appearing to almost skip across the sky and often flaring several times before fading away. Some fireballs can be so bright they cast shadows, with others leaving behind a ghostly trail of smoke that twists and turns for several minutes before vanishing.

DID YOU KNOW?
Encke and the Taurids are considered to be the remnants of a much larger comet that broke apart 20,000 to 30,000 years ago.

Stuart Atkinson
Science and astronomy writer
Stuart is the author of *A Cat's Guide to the Night Sky*, published by Laurence King Publishing. He has been observing the night sky for many years

Daisy Dobrijevic
Staff Writer
Daisy is **All About Space**'s Staff Writer. She previously worked for *BBC Factual* as a researcher and *BBC Sky at Night* magazine as an editorial assistant.

TAP HERE TO PLAY

WHEN TO WATCH THE TAURID METEOR SHOWER

While most meteor showers are noticeably active for about a week, the Taurids have perhaps the longest duration of overall visibility. This year the Southern Taurids will reach their peak on 10 October, and the Northern Taurids will peak overnight on 11 to 12 November - though you may be able to see a few meteors in the weeks before and after the peak. This year's Northern peak coincides with a 55 per cent illuminated Moon, which will reduce the number of faint meteors visible, but won't be bright enough to drown out the brighter fireballs.

WHERE TO WATCH THE TAURID METEOR SHOWER

The Taurids are visible anywhere on Earth, except the South Pole. Though you will be able to see some from your back garden, you'll have a much better view if you can find somewhere dark, well away from light pollution.

HOW TO WATCH AND LOCATE THE TAURID METEOR SHOWER

The Taurids can be seen with the naked eye, so there is no need for binoculars or a telescope. Once you've found a dark-sky site, you'll need to wait at least half an hour for your eyes to adapt to the darkness. Then you will just have to wait until you see your first meteor. Watching a meteor shower – especially one with such low levels of activity as the Taurids – requires a lot of patience. Find a comfortable spot, wrap up in warm clothes and consider going with someone to keep you company while you wait.

The Taurids will be visible all over the night sky, and can be seen when the shower's radiant point – in the constellation Taurus - is above the horizon. In the UK the best displays are likely to occur around 01:00, when the radiant point is highest in the sky. While looking for the radiant point is a good place to start, make sure to also keep an eye on nearby constellations. Meteors closer to the radiant can actually be harder to spot, as they have shorter trails. If you look only at Taurus, you might miss the shooting stars with the most spectacular trails.

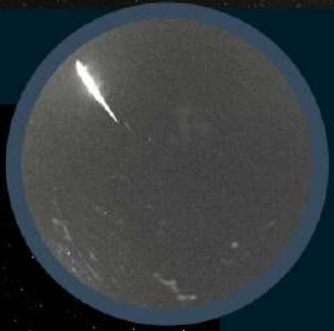
MONOCEROTID METEOR SHOWER
Active: 5 to 20 December
Peak: 8 December
Zenith Hourly Rate (ZHR): 2

SIGMA HYDRID METEOR SHOWER
Active: 3 to 15 December
Peak: 12 December
Zenith Hourly Rate (ZHR): 3

GEMINID METEOR SHOWER
Active: 3 to 16 December
Peak: 14 December
Zenith Hourly Rate (ZHR): 120

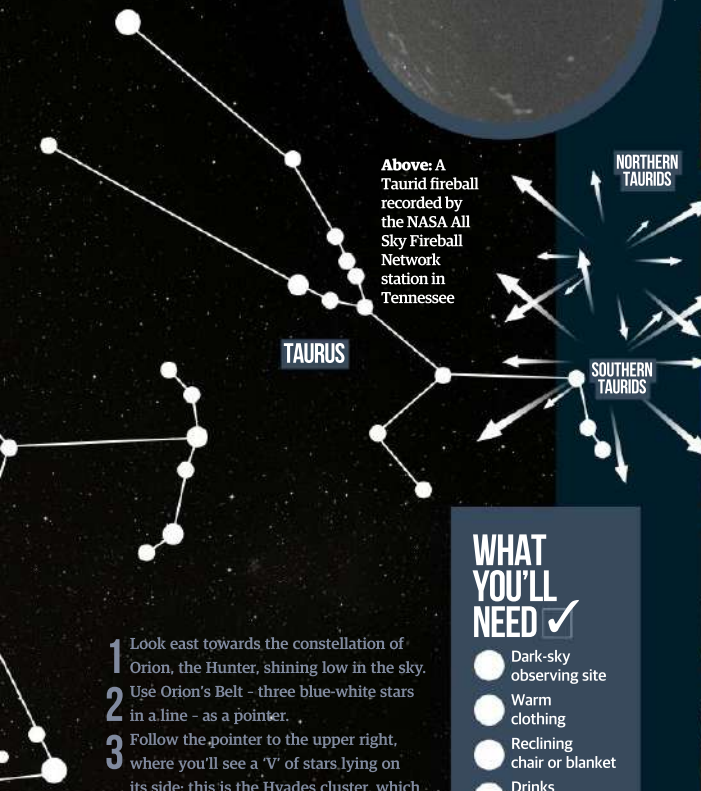
LEONIS MINORID METEOR SHOWER
Active: 5 December to 4 February
Peak: 19 December
Zenith Hourly Rate (ZHR): 4

URSID METEOR SHOWER
Active: 17 to 26 December
Peak: 22 December
Zenith Hourly Rate (ZHR): 10



© NASA

Above: A Taurid fireball recorded by the NASA All Sky Fireball Network station in Tennessee



WHAT YOU'LL NEED ✓

- Dark-sky observing site
- Warm clothing
- Reclining chair or blanket
- Drinks and snacks
- Binoculars (not essential)
- Red torch, pen and notebook
- Observing partners, if you'd like company

1. Look east towards the constellation of Orion, the Hunter, shining low in the sky.
2. Use Orion's Belt – three blue-white stars in a line – as a pointer.
3. Follow the pointer to the upper right, where you'll see a 'V' of stars lying on its side; this is the Hyades cluster, which represents the horns of Taurus, the Bull.
4. Further along, you'll see a thumbnail-sized knot of stars that looks like a mini version of the Big Dipper. This is the Pleiades star cluster.
5. The Taurid meteors all appear to zip away from just beneath the Pleiades.

KEEPING A RECORD

Take note of any very bright meteors you see streak across the sky

CHOOSE THE RIGHT LOCATION

Find an observing site with no light pollution and no tall trees, hills or buildings around it. The more open sky, the more meteors you'll be likely to see.

DRESS UP WARM

You will be outside a long time, so dress warmly and take a flask of something hot to warm you up when it gets chilly.

TRY TAKING SOME LONG-EXPOSURE PHOTOS

You can try capturing meteors in long-exposure photos taken with a camera on a tripod, but don't be surprised if you don't catch any.

MAKE A NOTE OF THE BRIGHTER METEORS

If you spot any bright meteors, try to record their details – direction, duration, colour and brightness. Meteor experts will find that very useful.

BE QUICK WITH YOUR BINOCULARS

Use your binoculars to zoom in on any glowing 'trails' left behind by the brightest meteors. They can be very colourful and last for several minutes.

TAKE A WALK

During the night there will be lulls in activity. Use these to walk around and get warm to keep you going through until dawn.

WHAT'S IN THE SKY?

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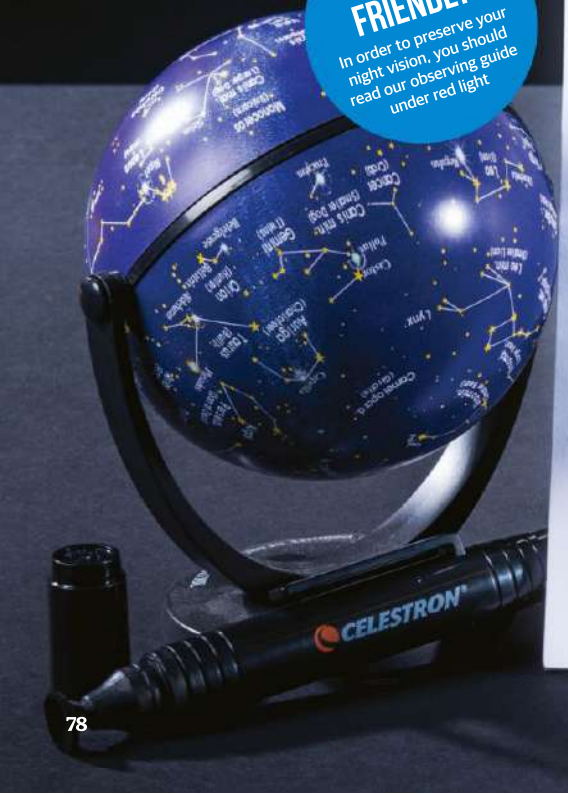
RED-LIGHT FRIENDLY
In order to preserve your night vision, you should read our observing guide under red light



"DURING GREATEST ELONGATION, THE INNER PLANETS CAN BE OBSERVED AS EVENING STARS AT GREATEST EASTERN ELONGATIONS"

8 OCT
The Draconid meteor shower reaches its peak

9 OCT
The Moon and Venus make a close approach, passing within 2°44′ of each other in Scorpius

10 OCT
The Southern Taurid meteor shower reaches its peak of five meteors per hour

15 OCT
The Moon and Jupiter pass within 3°56′ of each other in Capricornus

15 OCT
The Triangulum Galaxy (Messier 33) is well placed for observation in Triangulum at +5.7

17 OCT
Dwarf planet Eris reaches opposition in Cetus, glowing at magnitude +18.7

21 OCT
The Moon and Uranus make a close approach, passing within 1°14′ of each other in Aries

23 OCT
TAKE CARE!
Mercury is at half phase (dichotomy)

23 OCT
Venus is at half phase (dichotomy)

26 OCT
Open star cluster NGC 869 is well placed for observation in Perseus at +4.0

27 OCT
Open star cluster NGC 884 is well placed for observation in Perseus at +4.0

29 OCT
Venus reaches greatest elongation east in the evening sky, shining brightly at -4.4

JARGON BUSTER

Conjunction
A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)
Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)
This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude
An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition
When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation
When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

11 OCT
Saturn ends its retrograde – or backwards – motion in the night sky

11 OCT
The Delta Aurigid meteor shower reaches its peak of two meteors per hour

14 OCT
The Moon and Saturn pass within 3°50′ of each other in Capricornus

18 OCT
Jupiter ends its retrograde – or backwards – motion in the night sky

18 OCT
The Eta Geminid meteor shower reaches its peak of three meteors per hour

21 OCT
The Orionid meteor shower reaches its peak of 20 meteors per hour

23 OCT
The Leonis Minorid meteor shower reaches its peak of two meteors per hour

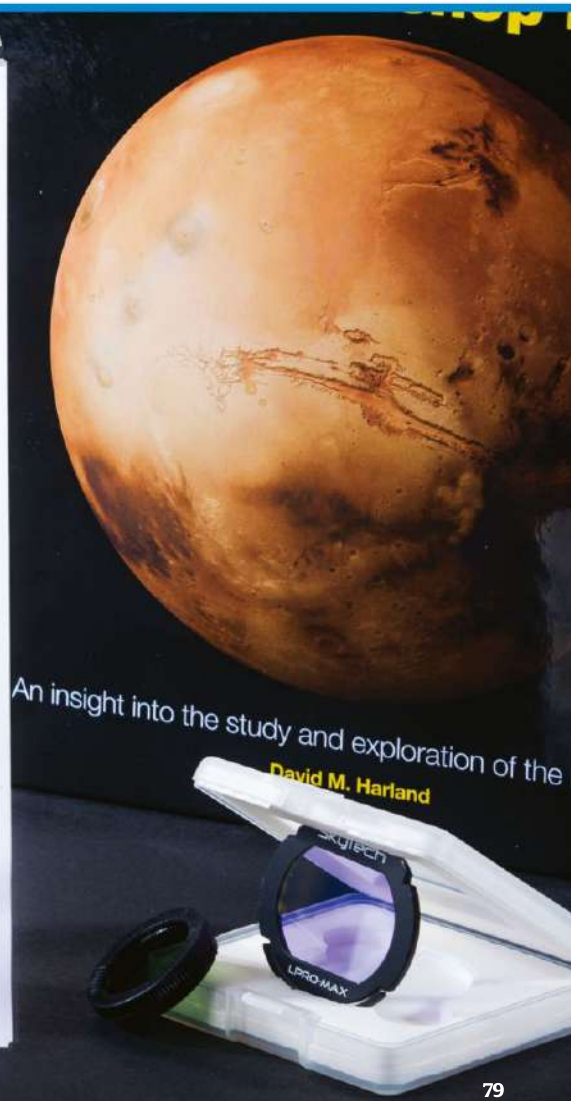
25 OCT
Mercury is at its highest altitude in the morning sky

25 OCT
Mercury reaches greatest elongation west in the morning sky, at magnitude -0.6

3 NOV
Comet 67P/Churyumov-Gerasimenko will make its closest approach to the Sun in Gemini

4 NOV
Uranus reaches opposition in Aries, glowing at +5.7

- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope



STARGAZER

PLANETARIUM

21 OCTOBER 2021

MORNING SKY

OPPOSITION

MOON CALENDAR

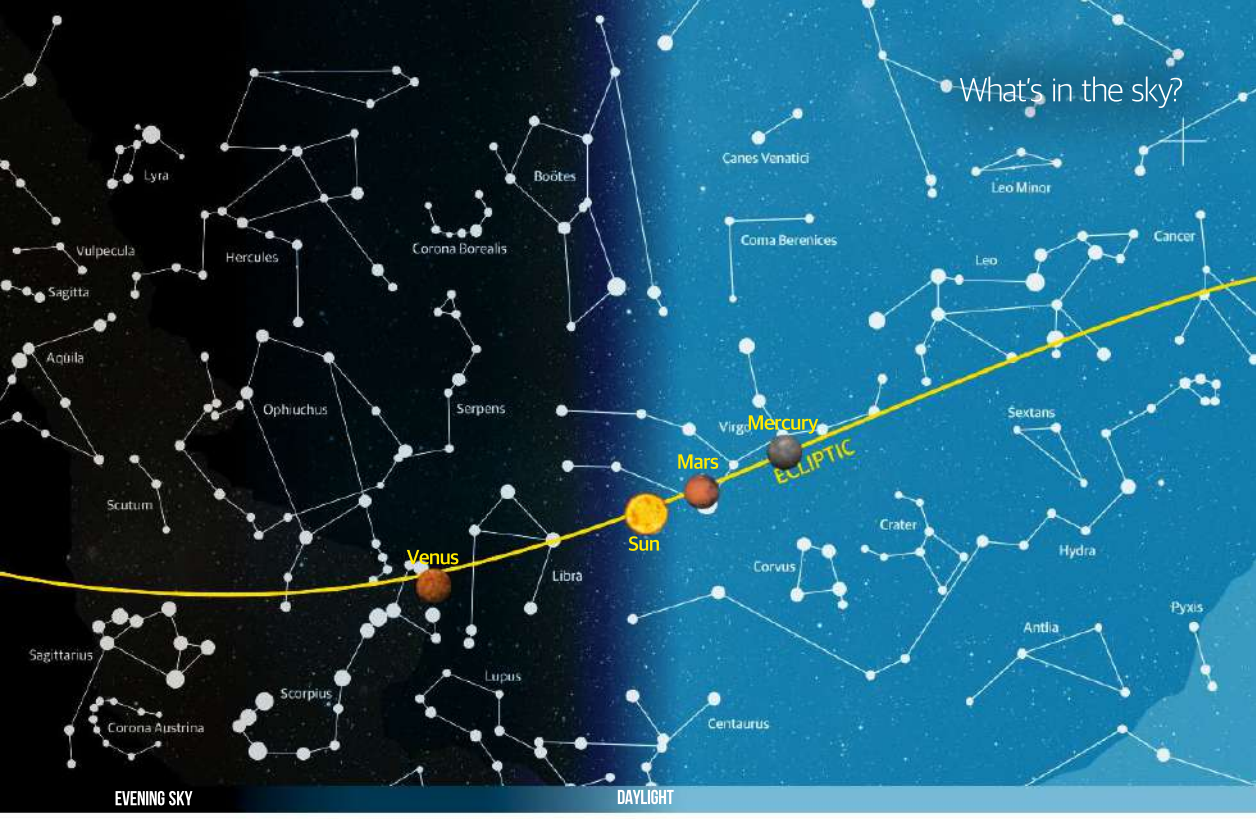
* The Moon does not pass the meridian on 19 October

7 OCT 1.7% 08:12 19:06	8 OCT 6.2% 09:40 19:26	9 OCT 13.5% 11:09 19:52	10 OCT 22.9% 12:37 20:26	11 OCT 33.9% 13:57 21:13	12 OCT 45.5% 15:03 22:14	13 OCT FQ 57.2% 15:53 23:27
14 OCT 68.1% 16:29 --:--	15 OCT 78.0% 00:46 16:55	16 OCT 86.2% 02:05 17:14	17 OCT 92.7% 03:23 17:31	18 OCT 97.1% 04:38 17:45	19 OCT --:--%* 05:51 17:58	20 OCT FM 99.5% 07:03 18:11
21 OCT 99.8% 08:14 18:26	22 OCT 98.1% 09:25 18:44	23 OCT 94.6% 10:36 19:05	24 OCT 89.4% 11:45 19:33	25 OCT 82.7% 12:50 20:09	26 OCT 74.7% 13:47 20:56	27 OCT 65.8% 14:34 21:54
28 OCT TQ 56.0% 15:11 23:02	29 OCT 45.8% 15:40 --:--	30 OCT 35.5% 00:15 16:02	31 OCT 25.5% 01:33 15:21	1 NOV 16.4% 01:53 15:37	2 NOV 8.7% 03:14 15:53	3 NOV 3.1% 04:39 16:09
4 NOV NM 0.3% 06:06 16:27						

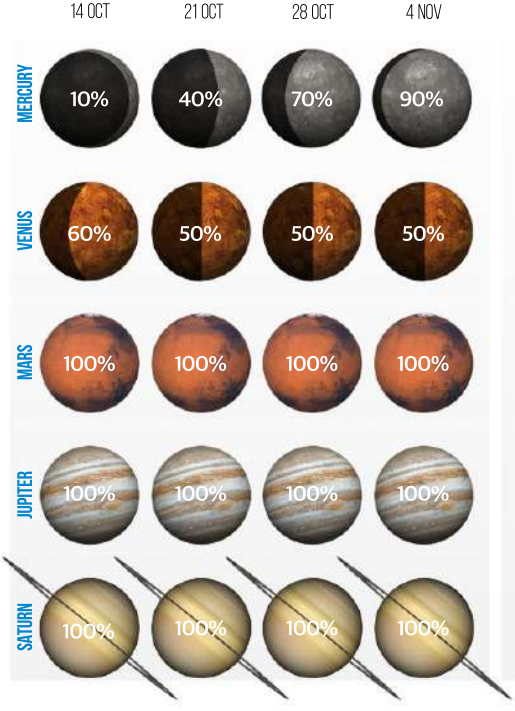
% Illumination
Moonrise time
Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Third quarter

* All figures are given for 00h at midnight (local times for London, UK)



ILLUMINATION PERCENTAGE



PLANET POSITIONS

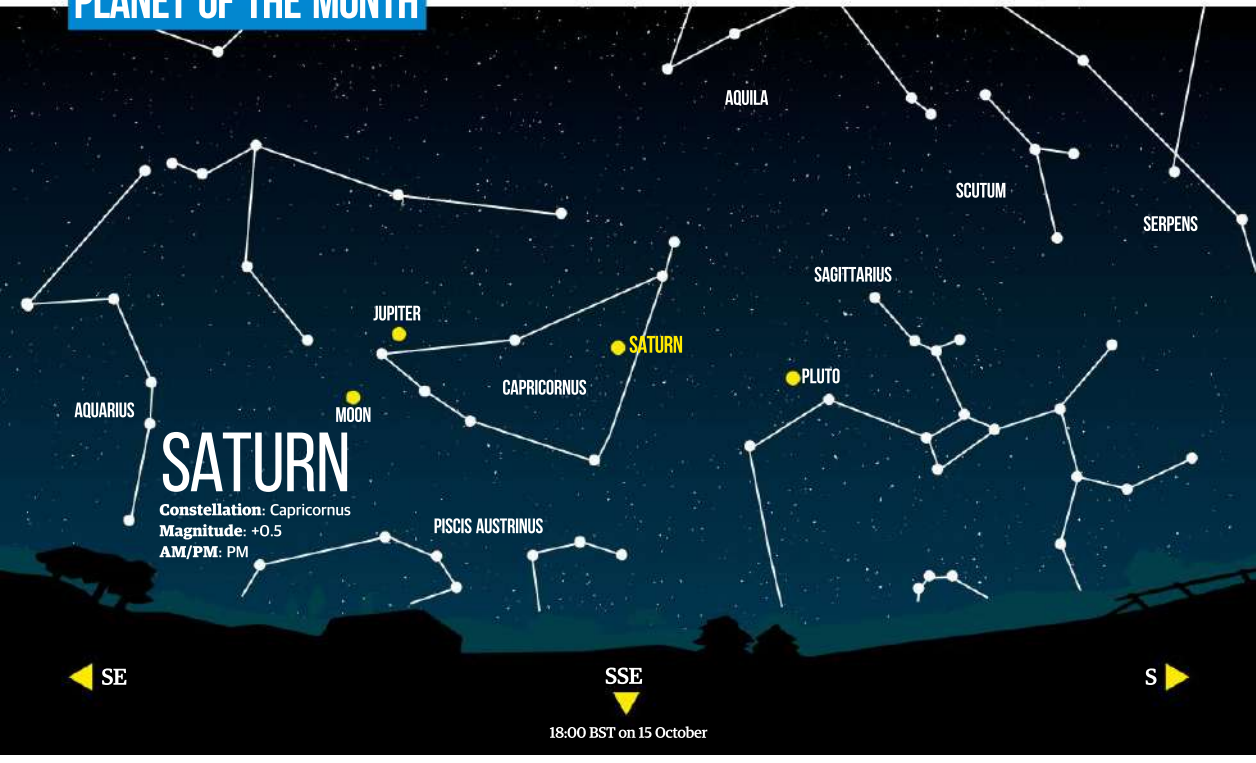
All rise and set times are given in BST/GMT

DATE	RA	DEC	CONSTELLATION	MAG	RISE	SET
7 OCT	13h 07m 33s	-10° 04' 03"	Virgo	+4.2	07:58	18:13
14 OCT	12h 42m 38s	-05° 03' 39"	Virgo	+2.8	06:40	17:47
21 OCT	12h 40m 14s	-02° 45' 24"	Virgo	-0.1	05:58	17:28
28 OCT	13h 04m 21s	-04° 33' 40"	Virgo	-0.8	06:03	17:16
4 NOV	13h 41m 40s	-08° 29' 18"	Virgo	-0.9	06:30	17:01
7 OCT	15h 45m 27s	-22° 29' 15"	Libra	-4.2	11:49	19:37
14 OCT	16h 17m 35s	-24° 23' 06"	Scorpius	-4.3	12:07	19:28
21 OCT	16h 49m 45s	-25° 49' 04"	Scorpius	-4.3	12:22	19:22
28 OCT	17h 21m 32s	-26° 45' 33"	Ophiuchus	-4.4	12:34	19:18
4 NOV	17h 52m 25s	-27° 12' 09"	Ophiuchus	-4.5	12:37	19:14
7 OCT	12h 52m 40s	-04° 55' 26"	Virgo	+1.6	07:16	18:25
14 OCT	13h 09m 44s	-06° 44' 38"	Virgo	+1.6	07:15	18:05
21 OCT	13h 27m 01s	-08° 32' 03"	Virgo	+1.6	07:14	17:46
28 OCT	13h 44m 34s	-10° 17' 05"	Virgo	+1.7	07:13	17:26
4 NOV	14h 02m 26s	-11° 59' 05"	Virgo	+1.7	07:09	17:04
7 OCT	21h 40m 07s	-15° 11' 29"	Capricornus	-2.7	16:57	02:20
14 OCT	21h 39m 14s	-15° 14' 54"	Capricornus	-2.6	16:29	01:51
21 OCT	21h 39m 09s	-15° 14' 22"	Capricornus	-2.6	16:02	01:24
28 OCT	21h 39m 42s	-15° 10' 35"	Capricornus	-2.6	15:34	00:53
4 NOV	21h 40m 53s	-15° 03' 38"	Capricornus	-2.5	15:03	00:24
7 OCT	20h 36m 47s	-19° 24' 56"	Capricornus	+0.5	16:19	00:48
14 OCT	20h 36m 45s	-19° 25' 02"	Capricornus	+0.5	15:52	00:20
21 OCT	20h 37m 04s	-19° 23' 52"	Capricornus	+0.6	15:25	23:53
28 OCT	20h 37m 42s	-19° 21' 27"	Capricornus	+0.6	14:57	23:26
4 NOV	20h 38m 41s	-19° 17' 48"	Capricornus	+0.6	14:27	22:56

THIS MONTH'S PLANETS

As the Red Planet dips below the horizon, observers can turn their attention to Saturn, a breeze to find through October and November

PLANET OF THE MONTH



Even though it's not the brightest planet in the sky, and never rises particularly high, Saturn will be well placed for observation and very easy to find. It will be a very easy naked-eye object this month, brighter than many of the stars in the sky. But its position in the zodiacal constellation of Capricornus means it will never reach a very high elevation, and might be hidden by tall buildings, trees or hills that are on your southern horizon.

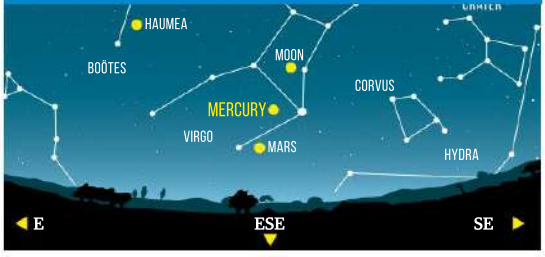
All through the month – and for some time to come – Saturn will be found to the right of Jupiter. It's easy to tell the two apart: Jupiter is a vivid, blue-white spark, while Saturn is much fainter and less striking, and also has a warmer, more golden hue than brash Jupiter.

Although Saturn is in quite a bare and barren constellation, making it even easier to pick out from the background stars, just over to its right you'll see the frothy star clouds of the Milky Way's almost-central region in neighbouring and much busier Sagittarius, so the planet is a useful stepping stone towards those. But Saturn itself is still lovely to look at this month, visible from sunset through to the late evening hours, setting before 23:00.

You'll see it as a yellow-white 'star' low in the south as soon as twilight darkens enough to allow you to see stars in the sky. To the naked eye it will look like a gold-hued star low in the southern sky during twilight, shining just above and to the left of the famous 'Teapot' asterism formed by Sagittarius' brightest stars. Binoculars will enhance Saturn's subtle warm colour and show it framed by countless fainter background stars, but if you want to see its rings you'll need a small telescope, as all but the most powerful binoculars are inadequate for seeing those.

The view through a telescope is magical though, and the rings look like a huge hula hoop thrown over the planet. The larger the telescope you look through, the more detail you will see within the rings. With enough magnification and a large enough aperture you will be able to see several dark gaps in the bright rings, and many of the planet's extended family of moons, too.

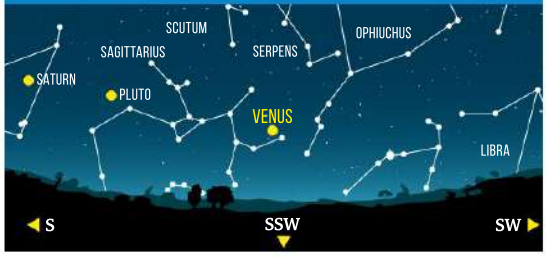
MERCURY 07:00 GMT on 3 November



Constellation: Virgo **Magnitude:** -0.9 **AM/PM:** AM

At the start of our observing period Mercury, the closest planet to the Sun, will be a morning object very low in the east, rising around an hour before the Sun. Its visibility will steadily improve; by the middle of October it will have brightened considerably to -0.8 and will be rising almost 90 minutes before sunrise, so will be visible in a darker sky.

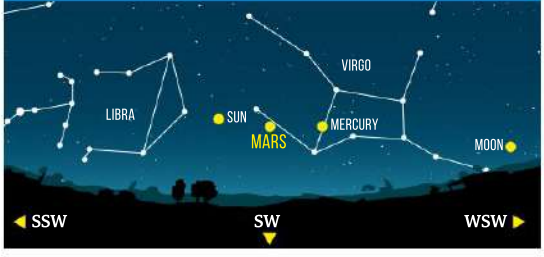
VENUS 16:00 GMT on 3 November



Constellation: Sagittarius **Magnitude:** -4.2 **AM/PM:** PM

This will be a good month for you if you enjoy seeing Venus, because although it will be very low in the sky after sunset, never straying out of the twilight, it should still be bright enough for you to see it with your naked eye all through our observing period – at least providing there aren't any hills, trees or tall buildings on the horizon to your southwest.

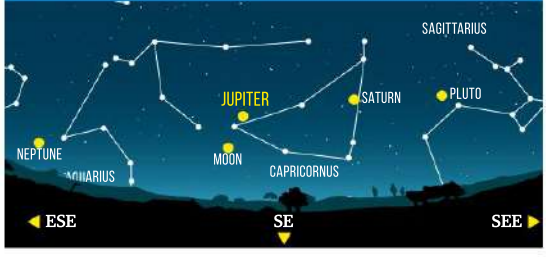
MARS 03:00 GMT on 1 November



Constellation: Virgo **Magnitude:** +1.6 **AM/PM:** AM

This will not be a good month for sky-watchers to see Mars from Earth. Technically the Red Planet will be a morning object during our observing period, but shining at just brighter than second magnitude, very low in the predawn sky, it will be very hard to see, especially if you have anything less than a perfectly flat horizon.

JUPITER 18:00 BST on 15 October



Constellation: Capricornus **Magnitude:** -2.7 **AM/PM:** PM

Behemoth gas giant Jupiter is the most obvious and striking planet in the sky this month, easily visible to the naked eye as a bright, blue-white 'star', and a splendid sight in even a modest pair of binoculars. Jupiter will be low in the southeastern sky as soon as the Sun sets and the first stars begin to come out, and will be visible all through the evening.

URANUS 19:30 BST on 22 October

Constellation: Aries **Magnitude:** +5.7 **AM/PM:** PM

Uranus is visible to the naked eye from Earth, but only to those blessed with good eyesight, night skies free of light pollution and a good star chart. At +5.7 it is just visible to the naked eye as one star among many, but a pair of binoculars is very useful for helping to identify it because they enhance its pale-green colour. This month Uranus will be visible all night.

NEPTUNE 19:30 BST on 22 October

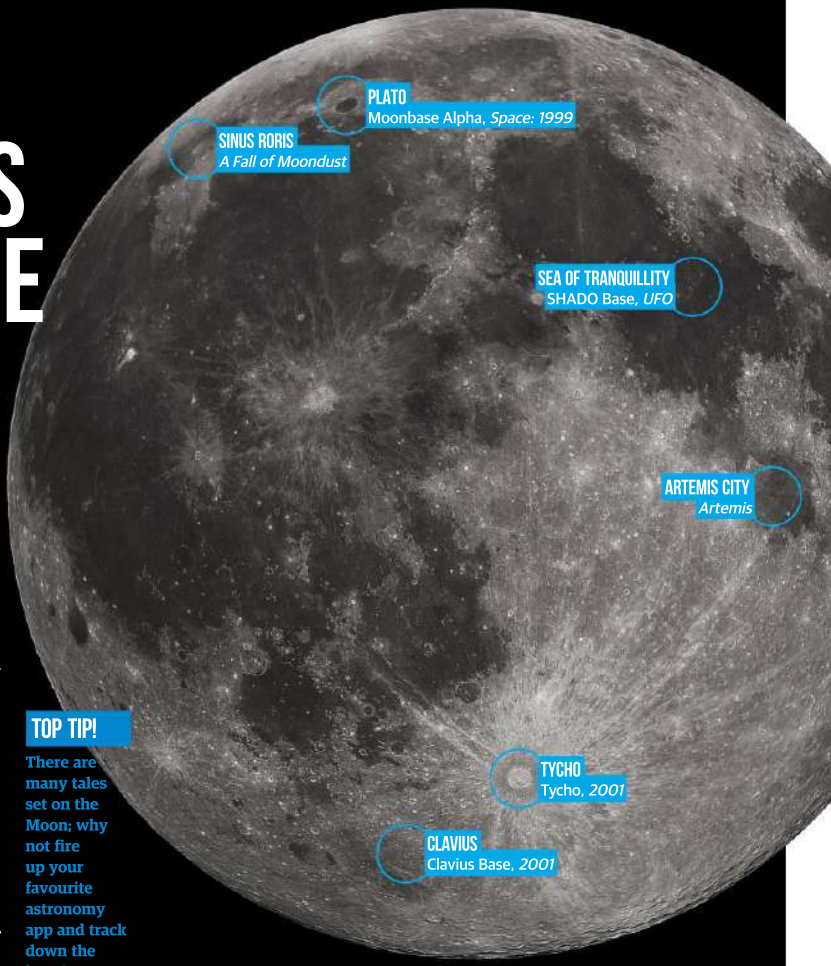
Constellation: Aquarius **Magnitude:** +7.8 **AM/PM:** PM

At magnitude +7.8, Neptune is too faint to be visible to the naked eye, even under a clear, dark sky. A pair of binoculars will pick it out, looking like a tiny, blue-green star surrounded by much brighter stars. This month Neptune is visible from sunset, and won't set itself until the sky begins to brighten with the approach of dawn, but finding it will be challenging.

MOON TOUR

LOCATIONS OF SCIENCE FICTION

Track down some of the most famous places to be found in the Moon's sci-fi stories



TOP TIP!

There are many tales set on the Moon; why not fire up your favourite astronomy app and track down the locations?

The Moon has featured in too many books, films and TV shows to count... not all of them classics by any means. However, a few really do stand out, and it's fun to use binoculars and telescopes to hunt down the locations featured in them – we're going to point you towards some of them.

First, the 1968 film *2001: A Space Odyssey* features not one but two famous lunar locations. At the start of the film Dr Heywood Floyd is seen travelling to a beautiful, rotating, ring-shaped space station in a sleek space shuttle, with *the Blue Danube* playing in the background, before departing for the Moon on board a rather less glamorous but much more functional lunar shuttle. Upon his arrival he descends to a sprawling Moon base, complete with its own spaceport, tower blocks and conference rooms. This is Clavius Base, and as its name suggests it can be found within the crater Clavius. Clavius can be found down to the bottom of the Moon's disc, below and to the left of the crater Tycho and its bright rays.

Tycho itself is the second location featured in *2001*. Floyd travels from Clavius Base to Tycho to see for himself a strange artefact that has been discovered beneath that crater: a black monolith, left there by an alien intelligence millions of years before. Tycho crater is one of the easiest features to find on the Moon, especially near full Moon when its bright rays spray away from it for miles like paint or chalk dust.

Moving on to sci-fi literature, one of the most famous – and best – novels written about life on a colonised Moon is *A Fall of Moondust* by Arthur C. Clarke. In this beloved 1961 book, the 'Selene', a vehicle that carries tourists across the lunar seas, gets trapped in a quicksand-like pool of moondust. Only the quick thinking and heroism of the Selene's brave young captain and its plucky chief stewardess save the day. The action takes place in Sinus Roris, a minor sea that can be found very close to the top limb of the Moon, looking like a long, dark patch just above the curved, cut-out basin of Sinus Iridium.

Moving on to TV, fans of Gerry Anderson will be aware that not one but two of his series featured locations on the Moon. Between 1970 and 1973, *UFO* showed brave members of the top-secret organisation SHADO – some dressed in sparkly purple wigs – coordinating efforts to prevent attacks by sinister aliens from their Moon base in the Sea of Tranquillity, not far from the historic landing site of Apollo 11. Years later, *Space: 1999* had another Moon base, this time a huge one, four kilometres (2.5 miles) wide and a kilometre (0.62 miles) deep. Moonbase Alpha – which looked very similar to *2001*'s Clavius Base – was constructed inside Plato, one of the most prominent features on the Moon, which can be found to the right of Sinus Iridium, up near the top limb of the Moon. In *Space: 1999* the Moon is famously blasted out of Earth's orbit and flung off on a journey to the stars after nuclear waste stored on the Moon's 'dark side' explodes in spectacular style.

Finally on this tour of amazing sci-fi places, we return to the Sea of Tranquillity. Andy Weir followed up his hugely successful novel *The Martian* with *Artemis*, a story set on the Moon in the sprawling city of Artemis, population 2,000, which like SHADO's secret Moon base can be found close to the Eagle's landing site.

NAKED EYE & BINOCULAR TARGETS

Glittering stars and spectacular spiral galaxies are easy finds in the night sky

5 The Pinwheel Galaxy (Messier 101)
One of the most observed galaxies in the sky, Messier 101 is known as the 'Pinwheel' because of its almost-perfect spiral shape. It is thought to be twice the size of our own galaxy, the Milky Way, and is more than 27 million light years away. It is visible in binoculars as a faint patch of light.

2 Polaris, the Pole Star
Second-magnitude Polaris is the 48th-brightest star in the sky. It is directly above Earth's rotational axis, which means it is the only star that appears to stand still in the sky. Its nickname is 'the Pole Star', but it won't be that forever – by the year 14,500, Vega will become our new north star.

CORONA BOREALIS

DRACO

BOÖTES

2

URSA MINOR

3

5

1

4

4 The Whirlpool Galaxy (Messier 51)
This beautiful spiral galaxy, the same size as our own Milky Way, contains more than 160 billion stars and lies more than 23 million light years from Earth. It looks like a very small, round patch in binoculars, close to the star marking the tip of the Great Bear's tail.

URSA MAJOR

CANES VENATICI

COMA BERENICES

3 Arcturus (Alpha Boötis)
The fourth-brightest star in the entire sky, magnitude -0.05 Arcturus is a giant star almost 30 times wider than our Sun. Only 37 light years away – close in cosmic terms – its nickname is 'the Bear Watcher' due to its proximity to Ursa Major (the Great Bear).

1 Mizar and Alcor
One of the most famous double stars in the sky, Mizar and its close companion Alcor were once used as a test of good eyesight. Today we know they are actually six stars orbiting around one other, more than 78 light years from Earth.

California Nebula
(NGC 1499)

DEEP SKY CHALLENGE

EXPLORE PERSEUS AND CASSIOPEIA

A ghostly nebula and a rose-shaped star cluster are among your observing challenges this month

We've got some real observing challenges for our readers this month, with faint gems hidden among the bright, familiar stars of the much-loved constellations Perseus and Cassiopeia. However, with the sky staying bright until the late evening at this time of year, you'll need to stay up late or get up early to see them.

NGC 7789 is a loose cluster popularly known as 'Caroline's Rose'. Discovered by Caroline Herschel in 1783, its many loops of stars and the dark gaps between them give it – some observers claim – a strong resemblance to a white rose. See what you think when you have it in the middle of your telescope's eyepiece.

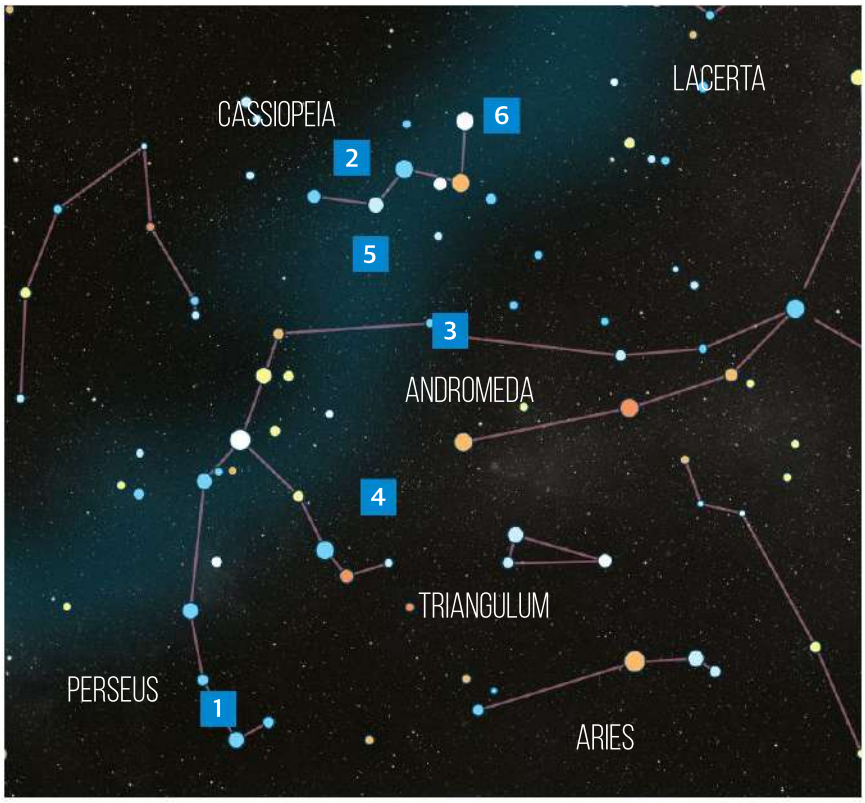
Messier 76 is a planetary nebula nicknamed the 'Little Dumbbell Nebula' and is infamous among deep-sky observers as one of the hardest to see of Messier's catalogue of 110 objects. It's definitely one for the owners of large-aperture 'light buckets' to try and hunt down.

Owners of small telescopes aren't left out, however. The pretty little magnitude +5.6 cluster Messier 34 is worth looking at through any telescope at any time.

Caroline's Rose
(NGC 7789)

Source: Wikipedia Commons ©Hewholooks

Source: Wikipedia Commons ©Remidone



Little Dumbbell Nebula (M76)

Source: Wikipedia Commons ©Vanderbei

1 The California Nebula (NGC 1499)
NGC 1499 is quite large, but its very low surface brightness means it is still quite hard to see in small telescopes. It is only seen properly through light-gulping medium or large-aperture instruments.

2 NGC 559
This ninth-magnitude loose open cluster in Cassiopeia contains several dozen stars and is best seen in medium-aperture or larger telescopes. It is 3,700 light years away and about four arcminutes across.

3 Little Dumbbell Nebula (Messier 76)
Magnitude +10.1 M76 is one of the most difficult to find of all of Messier's objects – only large instruments will show it in the field of view clearly. Despite its nickname it looks more like a misty elongated patch than a twin-lobed dumbbell.

4 Messier 34
Just north of the star Algol, M34 is a very loose open cluster of 100 or so stars covering the same size area as the full Moon. Small telescopes give the best view of the trio of arms coming from its centre.

5 Messier 103
This magnitude +7.4 open cluster is one of the sky's hidden gems. Small and medium-aperture telescopes give lovely views of the 'miniature Orion's Belt' across its centre – an orange star with an icy blue star on either side.

6 Caroline's Rose (NGC 7789)
The stars in magnitude +6.7 NGC 7789 are so densely packed that some think it looks more like a globular cluster than a loose one. Either way, medium and large-aperture telescopes are needed to see the stellar petals' subtle outlines.

"IT'S ONE OF THE HARDEST TO SEE OF MESSIER'S CATALOGUE OF 110 OBJECTS"

THE NORTHERN HEMISPHERE

Autumn is here, and with the darkened skies some astronomical favourites are brought into view

Circumpolar Cassiopeia (the Queen) and Cepheus (the King) lie in the dusty path of the Milky Way, offering not just a rich star field, but impressive deep-sky objects. The Owl Cluster (NGC 457) is easy to pick out with decent binoculars, its 75 to 100 bright stars forming the shape of an owl with spread wings, while bright double star Phi Cassiopeiae forms the eyes. Double star Alpha Cassiopeiae can easily be split into a stellar pair, resolving a bright, yellow primary and faint, blue secondary. Use the constellations of Pegasus, Aquarius and Pisces and you'll be able to locate Cetus (the Sea Monster), which contains the remarkable variable star Mira, or Omicron Ceti, as well as a wide selection of galaxies.

USING THE SKY CHART

This chart is for use at 22:00 mid-month and is set for 52° latitude.

1. Hold the chart above your head with the bottom of the page in front of you.
2. Face south and notice that north on the chart is behind you.
3. The constellations on the chart should now match what you see in the sky.

MAGNITUDES

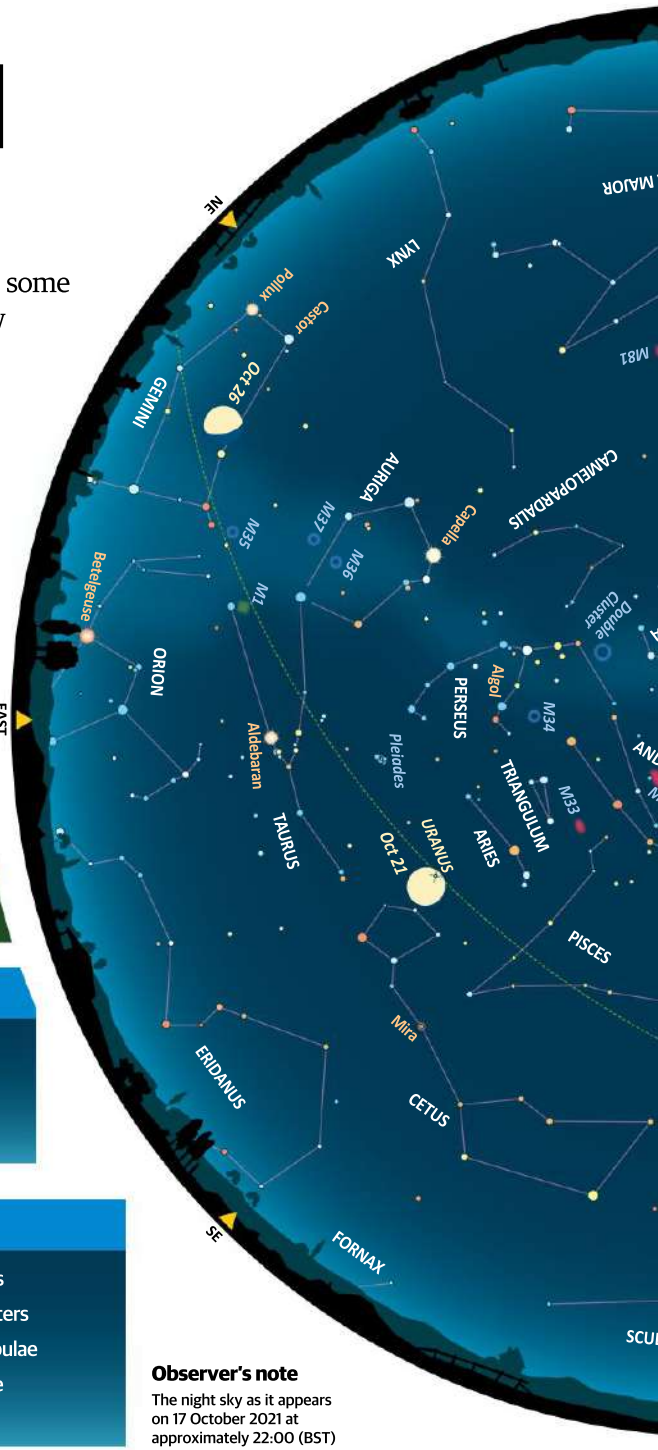
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

SPECTRAL TYPES

- O-B
- A
- F
- G
- K
- M

DEEP-SKY OBJECTS

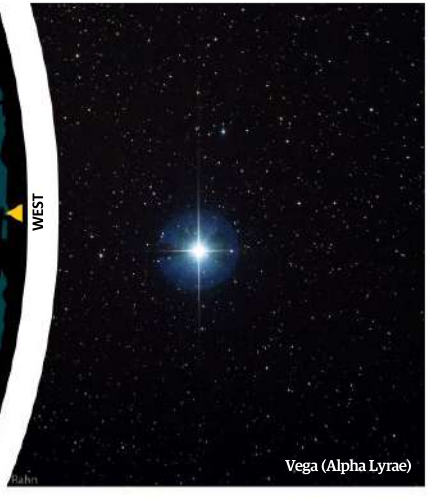
- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



Observer's note

The night sky as it appears on 17 October 2021 at approximately 22:00 (BST)

© NASA, ESA, the Hubble Heritage



Source: Wikipedia Commons © Stephen Rahn

© Getty

ASTROSHOTS OF THE MONTH

Get featured in **All About Space** by sending your astrophotography images to **space@spaceanswers.com**

Jeff Johnson

Location: Las Cruces, New Mexico

Telescope: Takahashi TOA-130 refractor

"I have a long love of astronomy, which began when I was ten years old, and I have observed the night sky for many years with binoculars and a telescope. I did my first 'real' astrophotography in 1996, when I used a 35mm SLR camera to take photographs of Comet Hyakutake. I took a tripod out into the desert here in Las Cruces and just experimented with different exposures. Later I bought a 10" Dobsonian telescope for observing the night sky, and within a week I was taking pictures through the eyepiece for fun. Within a few more weeks, I knew I wanted to get serious with astroimaging."

Above: Pinwheel Galaxy (Messier 101)

Right: Pleiades star cluster (Messier 45)

Jaspal Chadha

Location: London, UK

Telescope: Takahashi 106

"I have been imaging for around two-and-a-half years now after spending years looking through various telescopes and eyepieces, where I enjoyed learning all about the objects in the night sky. After months of research and trial and error, I finally invested in a set-up that I thought would work for me. My biggest challenge has been to fend off the myths around imaging in light-polluted areas, as I live in London. I started out with DSLR astrophotography, but now use a CCD to capture a wide range of night-sky targets."

Right: Bubble Nebula, Messier 52, NGC 7538, Sh2-157, NGC 7510, LBN 544

"AT THE HORIZON THE MOON WILL USUALLY BE A BLAZING ORANGE, AND I ALSO WANTED TO GET THE REDDISH TINGE OF EARTH'S SHADOW"

Premjith Narayanan

Location: Kingdom of Bahrain

"Knowing there would be a partial eclipse of the Moon rising from the horizon, I thought I could relate the eclipse to some terrestrial objects. At the horizon the Moon will usually be a blazing orange, and I also wanted to get the reddish tinge of Earth's shadow. Our planet's shadow covered 60 per cent of the Moon's surface, so I decided to select the highest point around the location to get a clear view of the seaside, along with any passing boats."

Right: Ruddy red colour of a lunar eclipse

REVIEW

NIKON Z6 CAMERA

The Nikon Z6 is part of Nikon's mirrorless suite of cameras, and when you combine price with performance, it's a real star in the night-sky photography world

Reviewed by Andy Hartup

CAMERA ADVICE

Cost: £1,399 / $1,599.95

From: Amazon

Type: Mirrorless

Sensor: 24.5MP backlit CMOS

Lens mount: Nikon Z (FX)

ISO range: 100 to 51,200 (before expansion)

Viewfinder size/resolution: 2.1k dots, 3.2-inch touchscreen

Video capability: 4K at 30fps

Weight (body only): 67 grams

Size (body only): 13.2 by 9.9 by 6.6 centimetres (5.2 by 3.9 by 2.6 inches)

Memory card type: Single-slot CFexpress, XQD

BEST FOR...

£ HIGH BUDGETS

LUNAR PHOTOGRAPHY

NIGHTSCAPES

If you're looking for a highly capable mirrorless camera for astrophotography, few models are better than the Z6. But the Z6 – which only launched in 2018 – has already been superseded by the Z6ii, so why are we testing and recommending the original model? It comes down to price and usage. For us, the original represents better value than the Z6ii, unless you're using it for video and high-intensity shoots, like weddings.

We love the Z6 for a number of reasons: it has a superb backlit sensor, perfect for low-light image quality, and a staggering 100 to 51,200 ISO range that delivers incredible clarity even in the darkest locations. Combine this with in-built image stabilisation and you've got one of the best cameras for astrophotography around. In fact, we'd say this is among the best mirrorless cameras for any use, so you'll be able to use it for way more than astrophotography. If you do want to use it for astrophotography, you may want to combine it with some of the best telescopes to get super-clear images. For beginners looking for an easy target, we recommend lunar photography to help you get to grips with combining your equipment.

When Nikon launched its mirrorless range, it was to allow the new Z-mount to improve not only the performance of the cameras, but also the feel and look. When you handle the Z6 without a lens, you'll notice it's significantly thinner and slightly lighter than most full-frame DSLRs. That reduced depth makes it easier to handle; if you're holding it for prolonged periods, this is a big advantage over traditional DSLRs. But once you add a lens that weight comes back. Despite the fact some Z-mount lenses are surprisingly light, you're unlikely to notice much difference in overall heft from traditional DSLRs. The overall handling for the Z6 is excellent, and Nikon's traditional grip design means you get a firm hold on the camera that's comfortable and practical, especially with the customisable shot-adjustment buttons within easy reach.

You'll find these custom buttons on the right of the lens mount, which means you can make quick adjustments to things like white balance without looking up from the viewfinder. There's the usual command dial, which has M, A, S and P modes along with three preset options, which allow you to program in settings you use regularly. We find this incredibly useful for things like shooting stars, where you're always looking for a 20-second shutter speed and wide aperture as standard.

The top set of buttons are completed by manual ISO control, an exposure button and a recording button for video. In addition to the adjustment wheel at the rear of the camera body, which is primarily used to make adjustments to shutter speed and ISO, there's a second wheel at the front of the shooting grip that allows you to control your aperture. When you're using the viewfinder, this setup really helps you focus on your shot.

When shooting the sky, most will rely on the monitor, and the Z6 has a great 3.2-inch display on the rear of the body. It's a touchscreen, and you can access all your menu items from here to make adjustments to your shot or settings. You can use the touchscreen to select a focus area, and even set it to shoot on touch. Our only real gripe is that it isn't as mobile as some – it attaches via the top of the screen and can't be rotated, so it's limited when you're shooting in portrait from a fixed position.

Main: The Z6 is fully customisable, and buttons can be mapped for personal shooting needs

Left: The 3.2-inch display is touch-controlled for easy use

"WE LOVE THE FEEL AND HANDLING OF THE Z6 – IT'S ONE OF THE BEST CAMERAS WE'VE EVER USED"

The Z6's body is fully weather-sealed, which means you can be out in moderate rain or wind for a few hours before you're likely to experience any problems. We even 'accidentally' dropped it in some river mud, and while it's tough to clean out of some of the indents in the camera body, this has never impacted performance. Elsewhere, there are clear markings for securing and changing lenses, and the seal between the camera and lens is tight and incredibly secure. The strap connectors are well made and manoeuvrable, too, so there's little danger of accidentally dropping the Z6.

Our main gripe with the design is the memory card slot. There's only a single card slot, and this camera doesn't accept standard SD cards like most models. The Nikon Z6 is compatible with CFexpress and XQD cards only, which is great from a performance perspective, but bad for your wallet. Even the cheapest 128GB CFexpress cards will cost you upwards of £110 ($150). One thing the Z6ii remedies is that it adds a second card slot and allows the use of SD cards.

We love the feel and handling of the Z6 – it's one of the best cameras we've ever used. While you'll find some with better touchscreens – and certainly save money on memory cards elsewhere – it's tough to complain about the design of the body. The Z6 is an absolute powerhouse when it comes to nighttime and low-light shooting, which is where we did the majority of our tests. While the 24.5MP sensor size is merely average among high-end mirrorless cameras, this won't compromise the quality of your landscape and night-sky photos.

What matters more is the ISO range, running from 100 to 51,200, and further expandable to between 50 and 204,800, and the clarity of the photos taken at higher ISO settings. Sharpness, noise and EV are remarkably consistent across the range, and compare extremely well to competing cameras. When you're shooting anywhere up to 12,800 ISO there's very little noise or softness to the image, and it only starts to degrade slightly on maximum and expanded settings. This is perfect for low-light situations like astrophotography, especially if you're trying to pick out unlit objects or scenery to give the night sky some context.

Combined with the in-built image stabilisation, which Nikon claims can compensate up to five stops, it means you can confidently shoot handheld in low light, because the incredible ISO will let you keep your shutter speeds high enough to retain clarity. We find it difficult to think of a better all-round camera when it comes to low-light shooting – the Z6 is actually one of the models used to

capture some of the best astronomy images in 2021 – the performance of the Z6 is only beaten by specialist astrophotography models in this area.

Elsewhere, the Z6 is capable of up to 12fps burst shooting for about four seconds at a time, which is about right for a camera of this price. While you probably wouldn't choose to use it over some of the Sony Alpha models for sports or motion photography, the Z6 still handles itself well in this area – it's just better for landscape photography and portraits. Shooting is super quiet and efficient. There's no interruption between shots like you find with DSLRs, and there's even a silent shooting mode for when you want to get discrete pictures.

In terms of autofocus, the Z6 is a very competent camera. It has 273 points of AF detection, and they cover 90 per cent of the view, which is decent coverage, and certainly enough for landscape photographers. This stat compares poorly to the Z7, but the coverage isn't a significant step down, and again it'll make little difference to night-sky images and landscapes. It focuses fast and accurately whether you're using the touchscreen or the viewfinder.

The Z6 is packed with features and functions designed to make your shots not only better, but easier to achieve. Given that this is a mirrorless camera, the touchscreen display is the most accurate way to shoot – unless you're in direct light or shooting a bright Moon. The viewfinder is a smaller simulation of the sensor image, so you'll find that it's actually slightly over-sharpened, and if you're shooting through the FTZ adaptor it can feel a little less natural, especially if you're using DX lenses.

We enjoyed using the touchscreen to focus the shot while in single-point mode in live view, and it's way easier than adjusting focus with the little stick while in viewfinder mode, but we didn't find much joy in using the touch-shooting. It's a neat feature that you'll play with at the start, but likely quickly ditch in favour of touch focusing.

While we're on the subject of the touchscreen, we found the auto-display switch mode very inconsistent, and wouldn't recommend using it – it seems to change modes randomly, which is a massive pain if you're lining up a shot. This adds the slightest of annoyances whereby you have to press the display switch button three times to move from viewfinder to monitor only. If you're rushed for time, this is irritating. Aside from that, it's easy to shoot with and cycle through the menus using the touchscreen.

Here you'll find all the standard options, like focus modes, metering and timers, as well as more advanced options like batch exposures, white balance adjustments and button customisation. In fact, the level of customisation is intimidating, as almost all the buttons on the Z6's body can be changed, and you have a whole roster of preset options for your command dial. This makes it a camera that suits highly specialised shooting, like astrophotography shots.

The Z6 has about a 320 to 330 shot battery life, which is about average for mirrorless cameras, so we'd recommend keeping a spare battery on hand if you're going to be shooting all day or night. When you consider this battery life with the single memory card slot, you realise this isn't a camera designed for intense shoots. It suits a slower pace, and a more considered shot.

If you're serious about astrophotography, landscapes or organised portrait shoots then the Z6 is perfect for you. What it lacks in sensor size and burst shooting, it more than makes up for in image stabilisation, ISO capabilities and pure handling feel. This is a camera designed for slower shoots in lower and natural light, and it's an absolute joy to use. We're willing to overlook small inconveniences like the memory card limitations and the lack of touchscreen mobility because the camera body itself is so capable, and isn't excessively priced. While we'd absolutely recommend the newer Z6ii for shooting video, as it can manage 4K footage at 60fps, the Z6 is virtually identical for photography and is about 20 to 30 per cent cheaper.

What's more, the full-frame Z lenses – especially the premium S-Line versions – are among the best camera lenses available right now, and they're beautifully designed. While they're eye-wateringly expensive, and the range is more limited than you'd find with the Canon and Sony units, you absolutely get what you pay for. Overall, we think you'll love the Z6 as an astrophotography and landscape camera... especially if you have the deep pockets needed to really make the most of it.

Right: The sturdy camera body works with a vast range of lenses

FOR
Superb ISO range for low-light shooting
Excellent in-built image stabilisation
Handles well, and the screen is bright and clear
AGAINST
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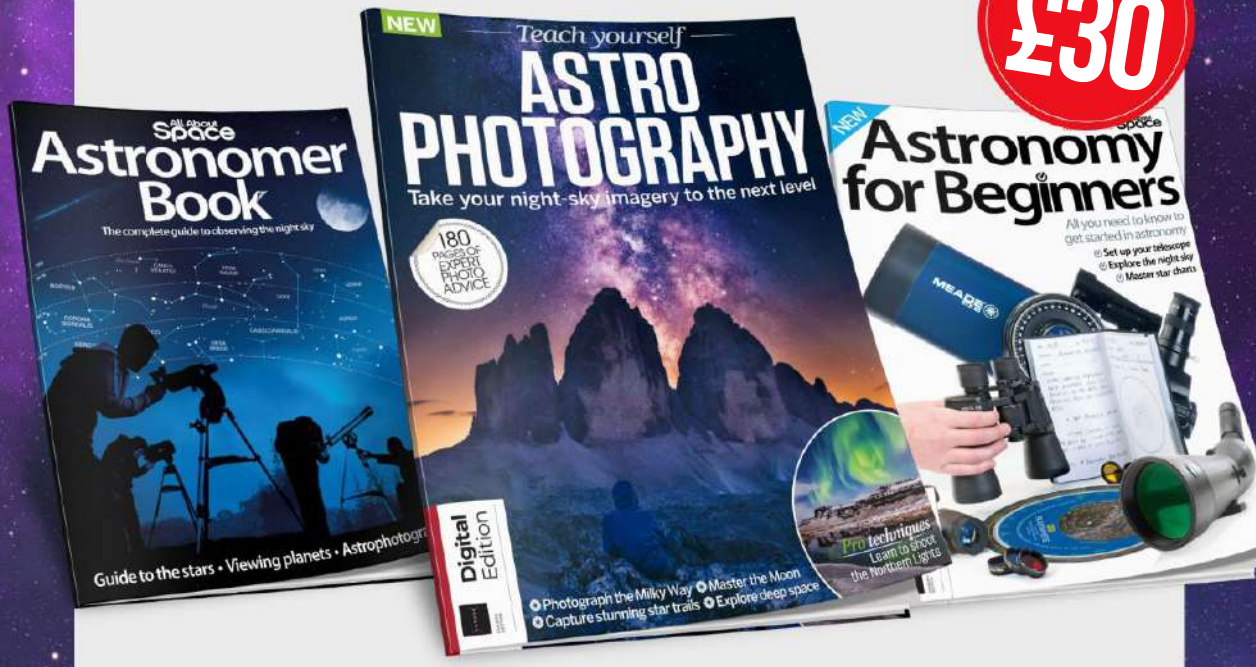

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Gazing up at the sky, you can get an idea of the wonders that our galaxy holds. With the naked eye you can see a sea of stars, behold the beauty of the Moon and map the constellations. But with a little guidance, there's so much more to enjoy. In this book, we start by helping you choose the best telescope and get set up, and guide you through the cameras that will help you get started in astrophotography. Take a tour through the universe as we show you how to view stars, moons, planets and more. You'll also find a comprehensive star atlas that will help you identify the constellations, no matter what time of year you're exploring the night sky.

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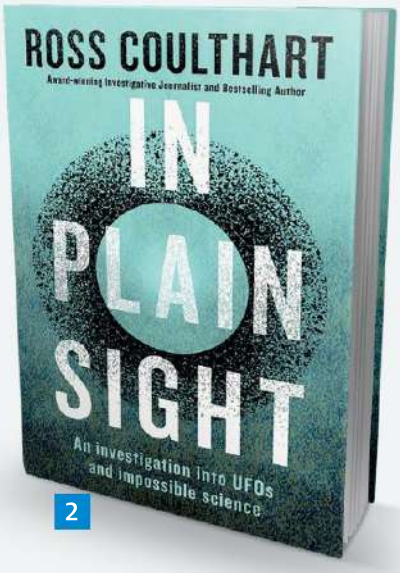
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2

3

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Cost: £16.99 / $19.99
From: Waterstones

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FOR OBSERVERS

ASTRO ESSENTIALS 32MM F/4 MINI GUIDE SCOPE

Cost: £59 ($81.20)
From: firstlightoptics.com

3 Locate your guide star with ease with this compact and lightweight guide scope. The guide scope works with most short to medium focal length imaging systems and conveniently comes with three mounting shoes, including one for Sky-Watcher scopes. It also has a long focus range, making it compatible with most guide cameras. Weighing in at just 287 grams, this guide scope won't adversely affect balance, providing a convenient guiding solution.

4

6

5

FOR ACCESSORISING

CELESTIAL MIDI DIAL SILVER MESH WATCH

Cost: £99 / $140
From: oliviaburton.com

4 Inspired by a faraway galaxy, this charming watch is one of the latest to join the Olivia Burton celestial watch collection, which contains over 20 cosmic-inspired timepieces. The dark-grey 30-millimetre dial features a sparkling spiral galaxy in the centre, surrounded by starry charms and mixed metal detailing, all enclosed in a stainless-steel case. This celestial watch is beautifully finished off with a luxe silver-toned mesh strap and would make a stellar gift for the space lover in your life.

FOR WORK OR SPECIAL OCCASION

BLACK SKINNY TIE WITH PLANETS

Cost: £19 ($26.15)
From: trendhim.co.uk

5 Looking for a tie with a subtle but effective space theme? This handmade skinny tie features an intricate planet design that is guaranteed to take your suit to the next level. Made from durable, soft polyester, this cosmic tie measures 148 centimetres (58 inches) in length and is six centimetres (2.3 inches) wide at the widest point. The simple colour palette means it is easy to match with most outfits. For even more accessorising options, the planet design is also available as a double-sided pocket square and a pre-tied bow tie from Trendhim.

FOR YOUR HOME

LE SOLEIL LA LUNE BATH MAT

Cost: £38 ($52.30)
From: anthropologie.com

6 Add a splash of je ne sais quoi to your home with this delightful hand-embroidered bath mat. A celebration of the Sun (le Soleil) and the Moon (la Lune), this whimsical tufted bath mat is the perfect accessory to brighten up those dark mornings. Measuring 83 by 55 centimetres (32.6 by 21.6 inches), the cotton bath mat can be machine washed on a cool and gentle cycle as well as tumble dried on a low heat. Due to the handmade nature of the item, no two will look exactly the same.

SVETLANA SAVITSKAYA

The second woman in space was also the first woman to perform a spacewalk

Savitskaya was an accomplished pilot before cosmonaut training

© Getty

Savitskaya was born in Moscow on 8 August 1948, inheriting her passion for flight from her father, Yevgeny Savitsky, who served as deputy commander of the Soviet Air Defence Forces. By the time she was 16, Savitskaya had decided that she wanted to be a pilot and applied to a flying school, though she was rejected because she was too young. She was, however, permitted to take up parachuting instead. By the time she was 17 Savitskaya had already completed 450 parachute jumps, and would soon take part in a record-breaking stratospheric skydive from 14,252 metres (46,758 feet).

Savitskaya's determined spirit and skydiving experience paid off when she was admitted to the Moscow Aviation Institute (MAI) at just 18 years old. In parallel with her studies at MAI, Savitskaya took flying lessons at the Central United Flight Technical School at the Central Committee of the DOSAAF, where she qualified as a pilot instructor in 1971. Savitskaya graduated from MAI in 1972, and went on to hone her skills at the aircraft department of the Test Pilot School of the Flight Research Institute of the Ministry of Aviation Industry in Zhukovsky, graduating from the institute in 1976. In 1986 Savitskaya successfully completed her doctorate degree at Bauman Moscow State Technical University.

Savitskaya racked up 18 world records in aviation, including a 2,683 kilometre (1,667 mile) per hour flight speed record for a female pilot in an MiG-25 aircraft. Throughout her time at MAI, Savitskaya was an active member of the Soviet national aerobatics team, where she became a world champion, and in 1970 was dubbed 'Miss Sensation' by the British press after her performance at the FAI World Aerobatic Championships in Hullavington, UK. Savitskaya's flying talent was not limited to aerobatics; the certified test pilot, second class, was qualified to fly over 20 different types of aircraft, and had impressively racked up over 1,500 hours of flight time before she was recruited as a cosmonaut.

When the Soviet Union set up a recruitment drive for female cosmonauts in 1979, Savitskaya was the perfect fit. She joined the cosmonaut training program in 1980 and was selected for the Soyuz T-7 mission to the Soviet space station Salyut 7. 19 years after Valentina Tereshkova became the first woman in space, Savitskaya followed in her footsteps. On 19 August 1982, Savitskaya flew alongside fellow cosmonauts Leonid Popov and Aleksandr Serebrov on the Soyuz T-7 spacecraft to Salyut 7. Their mission lasted eight days, and when the crew returned to Earth, Savitskaya made headlines as the second woman to travel into space, beating NASA astronaut Sally Ride by ten months.

Just two years later, on 17 July 1984, Savitskaya returned to Salyut 7 on the Soyuz T-12 mission alongside Vladimir Dzhanibekov and Igor Volk. During this mission, Savitskaya not only became the first woman to return to space, but was also the first woman to perform a spacewalk. After nearly 12 days in space, the crew returned to Earth. Soyuz T-12 would mark Savitskaya's last trip to space.

There were plans for Savitskaya to return to Salyut 7 as commander of an all-female crew for International Women's Day in 1986, but the mission was cancelled due to problems with the ageing station. Since her retirement from the cosmonaut corps in 1993, Savitskaya has led a successful political career.

Savitskaya is one of the most revered women in spaceflight history. She was twice awarded the title Hero of the Soviet Union, and also received two Orders of Lenin and the Order of the Badge of Honour in 1976. But Savitskaya's accolades are not limited to Earth: asteroid 4118 Sveta, which resides within the main asteroid belt, is named in her honour.

All About Space

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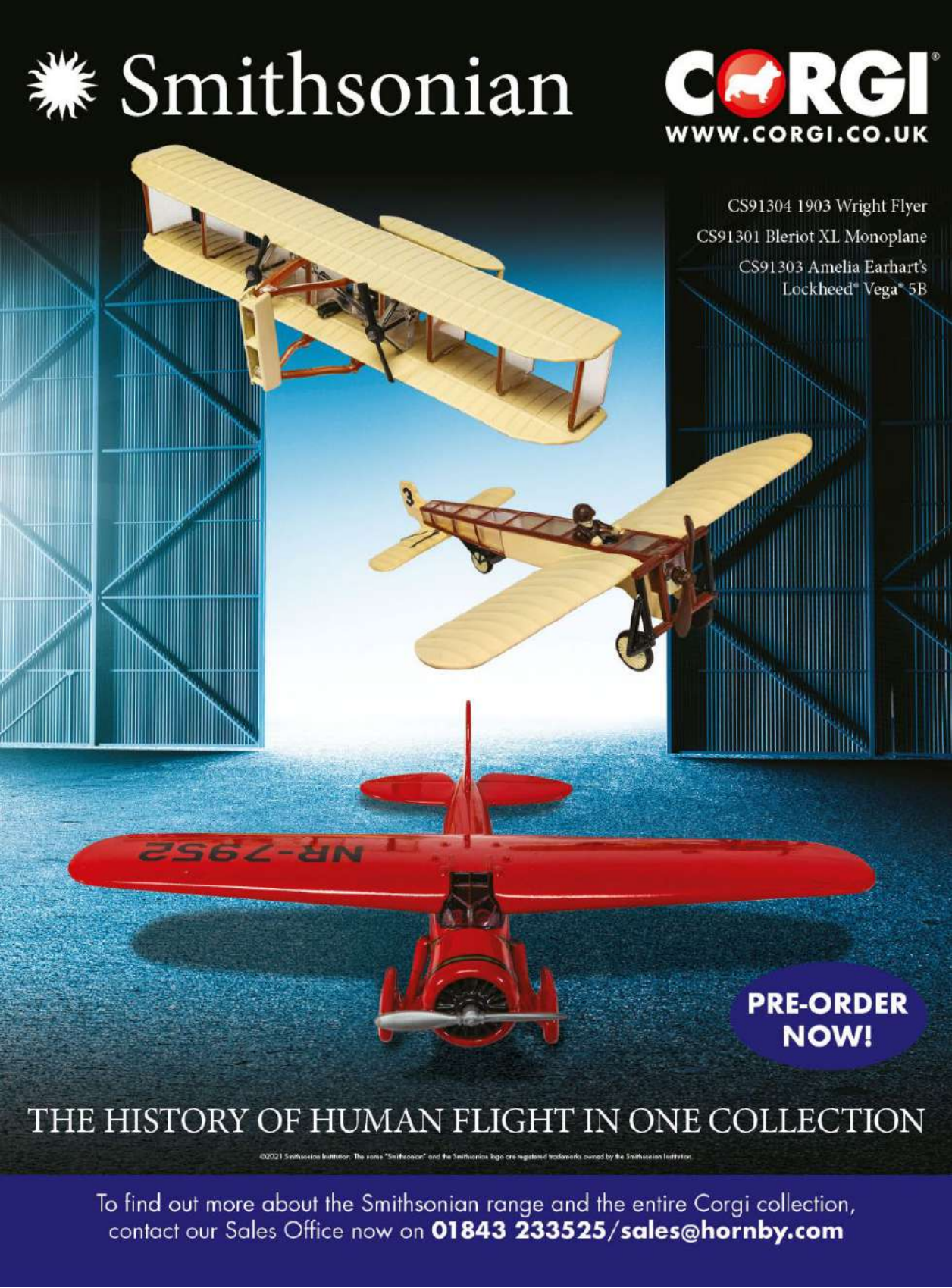
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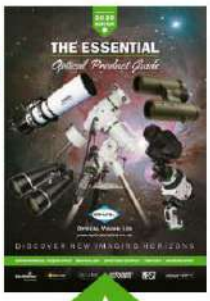

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